This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

LANE

MEDICAL LIBRARY

SEAL OF THE LELAND STANFORD JUNIOR UNIVERSITY

SEMPER VIRENS

1885

LEVI COOPER LANE FUND

LANE
MEDICAL LIBRARY
SEAL OF THE LELAND STANFORD JUNIOR UNIVERSITY
1885
LEVI COOPER LANE FUND

Entered according to Act of Congress, in the year 1878,
In the office of the Librarian of Congress, at Washington, D. C.

[illegible]

PHYSIOLOGY:

PRELIMINARY COURSE LECTURES,

BY

JAMES T. WHITTAKER, M.A., M.D.,

PROFESSOR OF PHYSIOLOGY AND CLINICAL MEDICINE IN THE MEDICAL
COLLEGE OF OHIO; LECTURER ON CLINICAL MEDICINE AT THE
GOOD SAMARITAN HOSPITAL; MEMBER OF THE CINCINNATI
ACADEMY OF MEDICINE, AND OF THE CINCINNATI
SOCIETY OF NATURAL HISTORY:

ON THE INFLUENCE OF PHYSIOLOGY UPON PRACTICE; ON
THE CONSERVATION OF FORCE; ON THE ORIGIN OF LIFE,
AND THE EVOLUTION OF ITS FORMS; AND ON PROTOPLASM, BONE, MUSCLE, NERVE AND BLOOD.

ILLUSTRATED.

LANE MEDICAL LIBRARY
17526
SAN FRANCISCO

CINCINNATI:
CHANCY R. MURRY, 103 W. Sixth St.
1879.

7.

Die Natur weisz allein was sie will.
Goethe; *Spruecke.*

* * *

To make man mild and sociable to man
To cultivate the wild licentious savage
With wisdom, discipline and liberal arts
Th' embellishments of life.
Addison; *Cato.*

I DEDICATE

This Little Book

TO THE

Students

AT THE

MEDICAL COLLEGE OF OHIO.

J. T. W.

71
N62
1879

PREFACE.

I have endeavored in the delivery of these lectures to put within the reach and comprehension of the first course student the foundation facts and principles upon which the stately edifice of physiology is built. And in the publication of them, which I have only presumed to venture in consequence of repeated requests on the part of the students of my class, I have adhered strictly to the spirit, and as far as I could, to the letter of the delivery. This explanation will suffice, I hope, to excuse the latitude of expression and selection which would be accorded to offhand, lecture-room, delivery, and which might be inexcusable in a text-book compiled for the more careful study of leisure hours.

J. T. W.

100 West Eighth St.,
Dec., 1878.

CONTENTS.

LECTURE I.

THE INFLUENCE OF PHYSIOLOGY UPON PRACTICE AND UPON THE PRACTITIONER.

Dr. Jacob Primrose—The Exercitatio de Motu Cordis, etc.—Science *vs.* Practice—The Fallacy of Experience—Some Old Receipts—Opinions of Noted Men—Sterne, Shakespeare and Molière—The Royal Touch and the Caul—Contributions of Physiology to Practice—The University of Naples—The Modern Physician—Gladstone's Response—Harvey and Haller—Characteristics of Physiologists........................1-23

LECTURE II.

THE CONSERVATION OF FORCE.

The Alphabet of Science—Indestructibility of Matter—No Matter without Force—Solar Origin of Heat of Coal—Correlation of Forces—Machinery, a Means of Changing Force—Clocks, Water-Wheels, Winds, Windmills and Steam Engines—The Equivalence of the Forces—The Conservatory of Arts and Trades—Motion from Heat—Motion from Electricity—The Electric Light—The Sun as the Source of Power—Source of Solar Force—The Nebular Hypothesis—The Channel of Mt. Pilatus—The Perpetuity of Force—Physiological Force—Excretions, the Products of Combustion—Animal Bodies as Machines—The Force Value of Foods—Physiological, Correlative with Physical Force..23-46

LECTURE III.

THE ORIGIN AND EVOLUTION OF LIFE.

Definitions of Physiology—Ancient Definitions of Life—Modern Definitions of Life—Difference between Organic and Inorganic Matter—The Property of Assimilation—Period of Development of Life—The Theory of Evolution—Palæontology—The Cataclysms of Cuvier—The Operation of Existing Causes—The Age of the Earth—The Evolution of Fossil Forms..47-63

LECTURE IV.

THE EVOLUTION OF FORMS OF LIFE.

Comparative Anatomy—Of the Eye and the Ear—Order of Development—Jean Lamarck—Wilhelm von Goethe—The Intermaxillary Process—Erasmus Darwin—Anatomical Resemblances—The Hand and its Homologues—Comparative Embryology—Ernst Haeckel—The Rudimentary Organs—Bone Rudiments—Muscle Rudiments—Rudiments from the Digestive System—Other Rudiments—Explanations of Rudiments......64-83

LECTURE V.

THE EVOLUTION OF FORMS OF LIFE.

The Law of Inheritability—Transmission of Acquired Defects—Homochronous Transmission—Atavism—The Physics of Reproduction—Adaptation to External Conditions—Difficulty of Classification—Artificial Selection—The Struggle for Existence—Natural Selection—Protective Colors—Warning Colors—Sexual Selection—Complications in Natural Selection—Preservation of the Individual and of the Race—General Summary......84-104

LECTURE VI.

PROTOPLASM AND ITS PROPERTIES.

The History of Histology—The Invention and Use of the Microscope—The Discovery and Doctrine of The Cell—Derivation and Import of The Cell—The Cell Wall—The Nucleus and Nucleolus—The Cell Contents or Protoplasm—The Amœba—The Properties of Protoplasm—Motion—The Color Changes of the Chameleon—Ciliary Motion—Motion of Other Cells—Molecular Motion—Molecular Changes in the Ovum—Parthenogenesis—Motion as the Essence of Reproduction...... 105-128

LECTURE VII.

PROTOPLASM AND ITS PROPERTIES.

The Chemistry of Organic Matter—The Ultimate Elements—The Proximate Principles—Albumen and its Products—The Chemistry of the Cell—Absorption and Assimilation—Metabolism—Oxidation Processes—Oxidation in the Ovum—Oxidation in Muscle—Oxidation in the Blood—Oxidation in Nerve Tissue—The Quantity of Oxygen in the Body—The Genesis of Protoplasm—Spontaneous Generation—Omne Vivum ex Ovo—Reproduction and Nutrition—Modes of Cell Genesis—Death of Cells—Recapitulation—Classifications of the Tissues...... 128-149

LECTURE VIII.

BONE AND ITS PROPERTIES.

Anatomical Dignity of Bone—Relation of Bone to Nerve Tissue—The Skeleton—The General Properties of Bones—The Histology of Bone—The Haversian Canals—The Lamellæ—The Bone Corpuscles and Lacunæ—The Canaliculi—The Chemistry of Bone—Difficulties Attending the Study of Osteology—Bones as Fuel—Gelatine as an Aliment—The Resistance and Resilience of Bone—Constancy of Chemical Composition—Rachitis and Osteo-Malacia—The Phosphate of Lime—The Preservation of Bone—Bone a Connective Tissue—The Formation of Bone—The Periosteum—The Centre of Ossification—The Determination of Age—The Femoral Epiphyseal Centre—The Excavation of Bone—Air in Bone—The Marrow—Studies in Living Bone—Bone as a Symbol of the Body..150-175

LECTURE IX.

MUSCLE AND ITS PROPERTIES.

Etymology of Muscle—Muscular Motion—Striped and Smooth Muscle—The Color of Muscle—The Anatomy of Voluntary Muscle—The Sarcolemma—The Muscle Fibre—Muscle Protoplasm—General Properties of Muscles—Names of Muscles—Form and Shape of Muscles—Smooth Muscle—Disposition of Smooth Muscle—The Chemistry of Muscle—The Reaction of Muscle—Specific Properties of Muscle—The Elasticity of Muscle—The Tonicity of Voluntary Muscle—Tonicity, a Reflex Phenomenon—Tonicity of Involuntary Muscle—The Sensibility of Muscle—Sensibility and Sensation—The Sensation of Fatigue—The Exercise of the Muscular Sense..........................175-195

LECTURE X.

MUSCLE AND ITS PROPERTIES.

Contractility of Muscle—Effects of Muscular Contraction—Degree of Contraction—Change of Form—Agents which Induce Contraction—Direct and Indirect Excitation—Thermal Excitation—Electric Excitation—The History of Galvanism—The Action of Induced Electricity—The Action of Nerve Force—The Sound of Muscle Contraction—The Muscular Wave—Independence of Muscular Force—The Action of the Sulphocyanide of Potassium and Curare—The Generation of Heat—The Generation of Electricity—Du Bois-Reymond's Theory of Muscular Action—Rigor Mortis—Post-Mortem Changes in Muscle—The Fuel of Muscle—The Oxygen Supply—The Dependence of Muscle upon Blood—The Muscles as Levers—The Absolute Power of Muscle—The Power of Muscle in General—Differences of the Sexes—Differences in Different Animals—The Velocity and Delicacy of Muscular Action.... 195-222

LECTURE XI.

NERVE AND ITS PROPERTIES.

The Prime Function of Nervous Tissue—Subordination to Other Tissues—Independence of Nerve Force—Genesis of Nerve Force—Arrangement of Nerve Tissue—White and Gray Matter—The Cerebro-Spinal and Sympathetic Systems—The Nerve Cells—The Nerve Fibres—The Neurilemma—The Axis Cylinder—The Gray Fibres—The Properties of Nerves—Terminations of Sensitive Nerves—Terminations of Motor Nerves—Course of Nerve Fibres—Identity of Nerve Fibres—Indifference of Direction of Nerve Force—The Chemistry of Nerve Tissue—The Action of Electricity upon Nerve Tissue—The Nature of Nerve Force—Rate of Conduction of Nerve Force—Nerve Force and Electricity—Comparative Velocity of Nerve and Other Forms of Force—The Reception and Perception of Impressions—Ancient Significance of Nerves—The Effects of Use and Disuse and of Age.......223-246

LECTURE XII.

THE BLOOD AND ITS PROPERTIES.

The Value of the Blood—The Transfusion of Blood—The Constitution of the Blood—The Color of the Blood—Reaction of the Blood—The Odor of the Blood—The Taste of the Blood—The Temperature of the Blood—The Weight of the Blood—The Quantity of the Blood—The Morphology of the Blood—The Red Blood Corpuscles—Size of the Red Corpuscles—Number of the Red Corpuscles—Elasticity of the Red Corpuscle—Constitution of the Red Corpuscles—Use of the Red Corpuscles—The Colorless Blood Corpuscles—The Blood Plasma—The Coagulation of the Blood—The Blood as the Substitute of the Body.......247-272

Index.......273-284

PRELIMINARY COURSE LECTURES.

LECTURE I.

THE INFLUENCE OF PHYSIOLOGY UPON PRACTICE AND UPON THE PRACTITIONER.

The Address Introductory to the Course on Physiology at the Medical College of Ohio, September 1, 1878.

CONTENTS.

Dr. Jacob Primrose—The Exercitatio de Motu Cordis, etc.—Science *vs.* Practice—The Fallacy of Experience—Some Old Receipts—Opinions of Noted Men—Sterne, Shakespeare and Molière—The Royal Touch and the Caul—Contributions of Physiology to Practice—The University of Naples—The Modern Physician—Gladstone's Response—Harvey and Haller—Characteristics of Physiologists.

Nobody in this hall ever heard, I venture to say, of Dr. Jacobus Primerosius. But Primrose made a good deal of noise in his day, and many were they who thought him a great physician. I pick out Primrose to-night from among all the notabilities of his time because he was a representative man. He made himself the exponent of his class. When the immortal Harvey proclaimed that startling truth about the circulation of the blood, which electrified the every-day world as well as the world of science and our branch of it to such degree that physicians met in counsel and gravely looked in each others faces and distressedly asked "what is now to become of us?" Primrose arose and said: "Pah! The Ancients made good cures before Harvey was born."

Thereupon Primrose proceeded to put Harvey down. Harvey had worked twenty years over his study before he could solve it to his own satisfaction. Then only did he preach his doctrine. He worked on nine years more. He repeated all his old experiments. He made new ones. He called in all his friends whom he considered competent and secured their confirmation. Then only did he publish it. Harvey was fifty years old, it was in 1628, when he published this first and of all the most brilliant triumph of experimental physiology. It was written in the purest spirit of science, expressed with an accuracy the most rigid and impressed with a modesty all through it in accord with its title. He called it

"An Attempt."

It was only a short manuscript, seventy-two pages in all, a fact in itself which put it in wonderful contrast to the gigantic folios of speculation composed at that time. There is a spirit of reverence all through it for the labors of his predecessors, especially for those of Galen. It lies now, the original paper, upon the shelves of the British museum; as to the truths contained in it, what child but knows that its heart beats with pulses of blood. There followed after Harvey in later years the next great man in physiology. This man, a Swiss, Albert Haller by name, said of Harvey: "His name is second only to Hippocrates." "*Libellus aureus,*" he said of his book.

Primrose felt towards Harvey, the keen envy of ignorance and pretense towards solid knowledge and sound truth. He hurried out his book under a high-sounding title in just fourteen days. The same Haller said of it: "It is subtle in cavil, in experiment empty." Harvey never noticed it at all.

I would like to use this incident in illustration of the subject of my theme. Had the respective studies of these two men, Primrose and Harvey (I will scarcely be pardoned now for mentioning their names together), anything to do with their characters as men and physicians.

Besides this vindication of the study of physiology I would like to use the opportunity to speak of the influence of physiology upon practical medicine as well as upon the status of the medical practitioner.

Science vs. Practice.

It may seem strange to the non-professional observer that there could be any possible question as to the general use of physiology. A man would hardly entrust his watch for repair to an operator who was not familiar with its mechanism and the manner of its work when in good working order, but there are those in the profession now, hard as it sounds, just as there were in Harvey's day, who believe, or affect to believe, that scientific investigation unfits a man for practice. John Aubrey, who was at Harvey's funeral and "helpt to carry him into the vault," writes: "I have heard him (Harvey) say, that after his booke of the Circulation of the Blood came out, he fell mightily in his practice, and t'was believed by the vulgar that he was crack-brained; and all the physitians were against his opinion and enoyed him. All his profession would allow him to be an excellent anatomist, but I never heard of any that admired his therapeutique way. I knew several practitioners in this town (London) that would not have given 3d. for one of his bills (prescriptions), and that a man could hardly tell by one of his bills what he did aime at." We shall see shortly how much to be admired was the "therapeutique way" of Harvey's contemporaries.

It is meet that we should consider these questions now while we stand on the threshold. If we can become fully convinced of the use of its study we shall enter with more earnest zeal. Nothing so dampens enthusiasm, so hampers progress, as doubt of the utility of the work.

I might, if I chose, content myself with merely pointing to the discovery of the circulation, the event which marked a new era in practical medicine. The skeptic must shut his eyes on this discovery before he can discuss the question at all.

Is there any disease or accident incident to man in the recognition or treatment of which we do not hold this element in mind like letters of the alphabet in reading the page. Take coarser facts. Could any one diagnosticate the character of a valve disease of the heart without a knowledge of the round of the circulation. Does not the treatment of wounded arteries or diseased, as in aneurism, by placing ligatures on the vessels between the heart and the accident or disease rest upon this established course of the torrent of blood. "The active mind of John Hunter," says Mr. Hodgson, "guided by a deep insight into the powers of the animal economy, substituted for a dangerous and unscientific operation, an improvement founded upon a knowledge of those laws which influence the circulating fluids and absorbent system; and few of his brilliant discoveries have contributed more essentially to the benefit of mankind."

But I do not wish to rely for our foundation simply upon the great corner stone. I would rather upon this occasion enter into some details that you may be impressed the more firmly, that rational practice is based on the disclosures of physiology, that you may be convinced that the art of medicine, practice, is, or is fast becoming, but a dependent upon its science, physiology.

The Fallacy of Experience.

Before any knowledge was possessed of the physiological action of medicines, disease could only be treated by empiricism. Experience was the great physician. See how blindly experience worked. Suppose I should read you a few receipts from the prescription books of some of the notabilities of their times, times close about that of the discovery of the circulation. It is the age of Shakespeare, of Francis Bacon, luminaries so glorious in literature and philosophy that there is still no defalcation in the lustre of their rays. And who was the representative man in medicine in that illustrious day? Theophrastus Paracelsus Bombastus. A name which has become the synonim of the grossest charlatany. He it was, who openly ridiculed all scientific investigation, who publicly burned the works of Galen and Avicenna and boasted that he treated disease by his superior intuitive knowledge. Maxwell, Greatrake, Digby, foremost men at this time, were theosophic enthusiasts who regarded diseases as the consequence of sin and the work of demons. It was the age of conjury and witchcraft and priestcraft. It was the period of the so-called ontological conception of disease. Diseases were peculiar beings or things with special properties or powers which had to be exorcised or conjured away. This doctrine held sway long after Harvey's day. It was only when the natural functions of organs had been fully described that the present physiological view, that disease proceeded from lesion of structure or function, was developed. So in the olden time there were special formulæ for special diseases. Bulleyn prescribed for a young child, suffering with some nervous disease, "a small young mouse roasted." Sterne writes: "My physicians have almost poisoned me with what they call *bouillons refraichissants*. 'Tis a cock flayed alive and boiled with poppy seeds, then pounded in a mortar and afterwards passed through a sieve. There is to be one craw-fish in it, and I was gravely told it must be a male one; a female would do me more hurt than good." Of one receipt, a regular salmagundi, from the Elizabethan age, its author remarks: "To tell the virtues of this water against colds, phlegme, dropsy, heaviness of mind, coming of melancholy, I cannot at this present, the excellent virtues thereof are such, and also the time were too long." Of another which contained gold and silver, sapphires and pearls, with spices and various perfumes: "This healeth cold diseases of ye brain, heart, stomach. It is a medicine proved against the tremblyings of the heart, fainting and swooning, the weakness of ye stomacke, pensiveness, solitariness. Kings and noble men have used this for their comfort. It causeth them to be bold-spirited, the body to smell well and engendereth good colour."

Even up to less than fifty years ago they bled patients for the cure of consumption. In the annals of Louis XIV, two centuries ago, is an account of the illness with consumption of one of the principal ladies of the court. On consultation, the doctors bled her in the arm. Next week they bled her again, this time in the temple. Strange to relate she was still worse on the following week, and the consultation was more anxious still. But there were resources in medicine in the days of the great emperor. The doctors bled her again, this time in the toe! They never bled her any more.

Small-pox was treated in accordance with the doctrine of signatures. The bed covers were red to bring the pustules to the surface. The bed furniture and bed-hangings were all red, and red substances were to be looked upon by the patient. The very drinks were red. John, of Gaddesden, physician to Edward II, directed his patients to be wrapped up in scarlet dresses; and he says that when the son of the renowned King of England (Edward II) lay sick of the small-pox I took care that every thing around the bed should be of a red color, which succeeded so completely that the prince was restored to perfect health without a vestige of a pustule remaining. About the middle of the seventeenth century, the doctrine of signatures was substituted by the system of expelling the peccant humors by the perspiration. We have a fine picture of this practice in the writings of Diemerbroeck, a Dutch physician and Professor. "Keep the patient," says Diemerbroeck, "in a chamber close shut. If it be winter let the air be corrected by large fires. Take care that no cold gets to the patient's bed. Cover him over with blankets. Red blankets have always been preferred—not that the color is material, but because in the times of our ancestors all the best, thickest and warmest blankets were dyed red. Never shift the patient's linen till after the fourteenth day, for fear of striking in the pock to the irrecoverable ruin of the patient. Far better it is to let the patient bear with the stench than to let him change his linen and thus be the cause of his own death. Nevertheless, if a change be absolutely necessary, be sure that he puts on the foul linen that he put off before he fell sick, and above all things, be sure that this semi-clean linen be well warmed. Sudorific expulsives are in the meantime, to be given plentifully, such as molasses, pearls and saffron."

Fantastic and nauseous things were used in the treatment of disease, the raspings of a skull for epilepsy, lizards, the excretions, etc., *ad nauseam.*

Opinions of Noted Men.

Is it any wonder that the shrewd author of Tristam Shandy should express his opinion of medicine and medical men in the manner in which he spoke of his treatment at the hands of the physicians of his day: "I was ill of an epidemic vile fever," he writes, "which killed hundreds about me. The physicians here are the errantest charlatans in Europe or the most ignorant of all pretending fools. I withdrew what was left of me out of their hands and recommended myself entirely to Dame Nature. She (gentle goddess) has saved me in fifty different pinching bouts, and I begin to have a kind of enthusiasm now in her favor, and in my own, that one or two more escapes will make me believe I shall leave you all at last by translation, and not by death." Is it any wonder that a man of Shakespeare's penetration (Shakespeare had been dead three years when Harvey announced his discovery) should depict for us his Dr. Caius in the Merry Wives of Windsor as a boisterous, blustering, ignorant knave, his Dr. Pinch in the Comedy of Errors as a poor fool whose beard is singed by an indignant patient, and whose sacred person is defiled by "great pails of puddled mire." Is it any wonder that he should tell his people, in another place, what to do with physic!

"Believe me," said Napoleon to Antomarchi, his physician at St. Helena, "we had better leave off all these remedies. Life is a fortress which neither you nor I know anything about. Why then throw obstacles in the way of its defense? Its own means are superior to all the apparatus of your laboratories. Corvisart candidly agreed with me that all your filthy mixtures are good for nothing. Medicine is a collection of uncertain prescriptions, the results of which, taken collectively, are more fatal than useful to mankind. Water, air, cleanliness, are the chief articles in my pharmacopeia." Molière most keenly satirised the credulity of his time in medical matters when he wrote: "*Il ne faut pas mourir sans l'ordonnance du medicin*" (Let no one dare to die without drugs from the doctor). Poor Molière fell upon the stage suffocated with hemoptysis, in the midst of his bitterest tirade against medical men. Whereupon an old physician remarked: "*Faites des comedies contre nous si vous* *voulez; mais la médecine vous defend de les jouer sous peine de la vie.*"

The Royal Touch.

Who has not heard of the glory and the grandeur of the reign of Louis XIV? How few of us know of the abject misery and horrible disease which all this glory and grandeur cost. History is full of its pomp and its ceremony. Let us read but one page of its ignorance and credulity.

The day is Sunday in early spring, Easter Sunday, 1686. The grand monarch is on the throne. Around him are the tapestries and clothes of gold, the rich hangings, the polished floors, mosaics, marbles, gold and precious stones. About him stand obsequeous countiers. Behold the King by the grace of God!

One thousand six hundred miserable wretches are crowded together outside the door. These are not subjects come to do homage at the foot of the throne. They are the maimed of limb, the blear eyed, the ulcerated. Shakespeare saw a crowd once like them; they were, he says, "strangely visited people, all swol'n and ulcerous, pitiful to the eye, the mere despair of surgery." They are come to the King to be touched for the King's evil, to be cured by being touched. What a picture this for the artist; the might and the splendor of majesty on the one hand, the loathsomeness and the degradation of disease on the other!

Touching for the King's evil was not confined to France. The numbers subjected to it during the reign of Charles II were almost incredible. The King had more patients, it was said, than all the physicians of his realm. The eagerness to obtain tickets of entry was such that in Evilyn's diary, March 28, 1684, it is written: "There was so great a concourse of people, men, women and children, to be touched for the evil that six or seven were crushed to death at the door. Yet, according to statistics, more people died of scrofula in this reign than in any other period, probably from neglect of all proper treatment. March 30, 1714, Queen Anne touched 200 persons, among whom was the celebrated lexicographer, Dr. Samuel Johnson, the most remarkable example, perhaps, of the utter failure of the cure. Yet Jeremy Collier, in his Ecclesiastical History of Great Britain, speaking of the many virtues and miraculous powers of Edward II, says "that this prince cured the King's evil is beyond dispute. He not only cured it, but transmitted the power of doing so as a hereditary miracle to all his successors. To dispute this matter of fact," he continues, "is to go the excess of skepticism, to deny our senses and be incredulous even to ridiculousness."

This author tells us of a Roman Catholic thus cured by Queen Elizabeth, who said, on being asked about it, that "he was now satisfied by experimental proof that the Pope's excommunication of her majesty signified nothing, since she still continued blessed with so miraculous a quality" (Pettigrew). This was the testimony of a learned man of his day. Where is there now such a fool as to believe in the value of a royal touch?

The Caul.

One of the most ridiculous, though perfectly innocent, of medical superstitions, which is worthy of mention because it is still cherished by the illiterate everywhere, is connected with the fragment of membrane sometimes born over a child's face, commonly known as a caul. This superstition has existed from the earliest times and the various imaginary virtues attributed to it have differed with every time and place. It is mentioned in the fourth century by Aelius Lampidius in his life of the Emperor Antoninus. Majolus attributes to the Roman lawyers the belief that the possession of a child's caul would make them eloquent and triumphant. It is spoken of by St. Chrysostom. In France it is an old superstition. *Etre nè coiffè*, "to be born with a caul," has always been considered a favorable omen. In Scotland it is called the holy hood. It is stated by Grose, that a person possessed of a caul, may know the state of health of the party who was born with it; if alive and well, it is firm and crisp; if dead or sick, relaxed and flaccid. In former days, the caul was the perquisite of the midwife who often traded upon the privileges it was supposed to confer upon the owner as a charm against drowning. As much as $150.00 has been paid for a caul. The London *Times*, of May 8, 1848, contained the following: "For sale, a child's caul. Price six guineas. Apply at the bar of the Tower Shades, Tower Street, London. The above article, for which fifteen pounds was originally paid, was afloat with its late owner thirty years, in all the perils of a seaman's life and the owner died at last at the place of his birth." A child's caul was advertised for sale in the Bristol *Times and Mirror*, September 30, 1874. The irrepressible Hood seems to have been fully aware of the popular recognition of its value which he combats in the tragic event which subsequently happened to its possessor.

> "But still that jolly mariner
> Took in no reef at all,
> For in his pouch confidingly
> He wore a baby's caul."

Contributions of Physiology.

Look with what tenacity the physicians of the empiric school clung to venesection. Long after they dared not practise it they persisted in preaching it still. Centuries upon centuries they put mercury into a man in whatever disease of the liver, blind to the fact that notwithstanding its administration for months in specific disease it in no way influenced the hepatic functions. And now it turns out that the liver after all was not the organ affected in almost all the cases. Scarce two teachers of materia medica taught the same action upon the heart under digitalis. Why? Because each gave his own experience. When regular physiological experimentation was commenced, it was not long before it was decided that it had only one action in all cases, namely, to increase the force of the heart's action, to diminish the frequency of its pulsations and restore its regular rythm. Let the most prejudiced observer read up the action ascribed to alcohol in fevers in different works on practice before the physiologist put it unchangeably down. Here it is advised to push it to the utmost; here to refrain from it altogether. Each man spoke from his own experience. Comes the physiologist with his thermometer. Alcohol lowers the temperature is the result of his experimentation, and the indication for its use is established. The surgeon used to cut and cut out the facial nerve, leave the face paralysed and deformed for facial neuralgia (tic douloureux) until the physiologist taught him that the facial was a nerve of motion, to the trigeminal he must look in disturbances of sensation. And then he would cut out this nerve down to its escape from the skull, excise the ganglion of Meckel, until he was again taught by the physiologist that this ganglion was only a reinforcing organ of the sympathetic system, and its ablation could in no way permanently cure the disease.

"The dangerous disease, to which many children have fallen victims, laryngismus stridulus, although admirably described by practical physicians, was never properly understood until the functions of the laryngeal nerves were clearly ascertained and until it had been shown that spasmodic actions may be excited by irritation of a remote part or through a stimulus reflected from the nervous centre. It is now known that this disease has not its seat in the larynx where those spasms occur which excite so much alarm for the fate of the patient; but that it is an irritation of a distant part, which derives its nerves from the same region of the cerebro-spinal centres as does the larynx—that the afferent nerves of that part convey the irritation to the centre whence it is reflected by certain efferent nerves to the muscles of the larynx." Do not these remarks bear with equal propriety upon epilepsy, chorea, hysteria and a host of kindred affections dependent in many cases upon reflex stimulus, a factor whose paramount importance is only recognised since the labors of the physiologists who first proclaimed it. How much advanced would we stand to-day in the management of gynæcological diseases beyond the time when the bloody issue was treated by touch, as in the New Testament, were it not for our knowledge of ovulation and its necessary consequence, as discovered and developed solely by physiological investigations. And in ophthalmology, that department which Virchow characterised in a late address before the British Medical Association as "that branch of medical science which has now reached the highest degree of scientific surety," how sensibly has treatment developed under the physiological investigations into the functions of different parts of the eye. Helmholtz, as is well known, and Græfe, forsook all other studies to work up the physiology of vision, and to these two observers, more than all others, are we indebted for the "scientific surety" which characterises practical ophthalmology. So I might continue for an hour and yet fail to enumerate the direct contributions of physiology to practical medicine within the past few years.

But if I should desire to put physiology in its proper light I should have to look out beyond the mere technical details whole social status of the physician. Even as late as the 15th century an apprentice would not be accepted in any of the mechanical arts unless he could prove that he was not the child of a butcher, executioner or a bleeder. The following old time advertisement clipped from a paper of Shakespeare's day thoroughly establishes the position of the every-day practitioner at that period: "Wanted.—In a family who have had bad health, a sober steady person in the capacity of doctor, surgeon and man mid-wife. He must occasionally act as butler and dress hair and wigs. He will be required sometimes to read prayers and to preach a sermon every Sunday. A good salary will be given." The modern dramatist, if he would reflect the sentiment of the people, exhibits the doctor in a rôle very different from the old time cunning knave or ignorant charlatan. A modern novel is scarcely perfect without a modern medical character. Witness, more especially, the best works of Bulwer and George Eliot. The chord so feelingly struck by the master hand of Lever has responded full and as feelingly to the magic touches of Dickens and Thackery. The physician is called, like Haller, to the chief position among the chairs of state. His profession is recognised by the highest civil authorities. Said Mr. Gladstone in a recent response: "and speaking of the body of the profession, even as an observer from without, it is impossible for us not to notice the change, it is impossible for us not to see how far more strongly now than of old, the medical man of to-day conforms to those general laws of common sense and prudence, which are, after all, universal laws of human life in every one of its departments. It is impossible not to see his greater and more sustained earnestness of purpose, that elevated sense of the professional dignity, that desire to make it subservient to the good of humanity, that general exaltation of his aims in the exercise of his profession."

And what is it that has thus lifted up the character of the physician in the eyes of his fellow-men? It is because the modern science of medicine is supported by the same kind of evidence as any other science. Evidence which may be sifted by instruments of precision, evidence which is tangible, demonstrable, indisputable. Such evidence is plain to the common understanding in whatever pursuit of life. It is evidence, to repeat the language of the distinguished statesman just cited, which conforms to those general laws of common sense, after all, the universal laws of human life in every one of its departments.

I do not know how I could better exhibit the influence of the study of physiology than by a very brief narration of some of the principal incidents in the lives of the two greatest of physiologists, Harvey and Haller, already cited. With both physiology was a life study. Each is known in medical history as having contributed a discovery by means of which we are chiefly guided in the treatment of disease; Harvey's, the circulation; Haller's, the knowledge that disease depends on lesion of structure or function.

William Harvey.—1578–1658.

Harvey was the oldest in a family of nine children. His parents belonged to the respectable middle class of society, that class from which has emanated, as is statistically proven, the greatest number of great men. With the rest of the family, he had that kind of training, which instils those virtues in childhood life, obedience and respect to authority and order, so characteristic of the English race, and without which excellence can be attained in no pursuit in life. With these traits, industry. That was all. But that is always enough. After leaving Cambridge, at the age of 21, he went to Padua to study under the great Fabricius, who gave him the first clue to his discovery by showing him the valves in the veins. What were these valves for? It was no flash of inspiration that answered this question for Harvey. It was solved, as has been stated, only after twenty years of patient, earnest toil. It was only the fact of his reputation as a worker that secured him any recognition at all at first. But there was a charm in Harvey's statements that could not fail to win him followers. It was the extreme modesty which characterises every line. When he could, he would support the opinions of those who had preceded him. When the truth forced him to differ, he did so, but with a delicacy the most sensitive, and with an array of proof that could leave no doubt of the correctness of his views. There have been to this day no corrections to make in Harvey's work, and there never since has been written a description of the circulation so comprehensive, so terse, so vivid. He was a worker so indefatigable and his works were so full of results that he soon acquired fame. The work of an earnest man is a synonim with fame. He was made a physician at St. Bartholomew's, a boy but 20 years of age. He was only 37—that was a youthful age in his day—when he was appointed professor of anatomy and surgery, and it was but a few years later that he became body physician to Charles I. He lived a life of the greatest simplicity and self-denial; Michael Angelo not more so. Much of his time he spent in perfect retirement with one or other of his brothers at their village homes. He declined the high honor of the presidency of the College of Physicians, though they succeeded in persuading him to allow his bust to be cast. At the age of 80, writes Haeser, the historian, he closed a life which had not been less glorious by the magnitude of his scientific labors than by his most rigid sense of justice, his exceeding gentleness and amiability of character and modesty of manner. "On

June 3, 1658, he died," said Spengel, our greatest historian, "but he left a name which is immortal. It is a name which posterity the most distant will never pronounce without experiencing a sentiment of veneration and of gratitude. It will shine with equal lustre with those of Aristotle, Fallopius and Haller. His industry, his prudence and his rare modesty, make of his character, eternally, a model, the most noble, for the naturalists, for the writers of all peoples and times."

Albert Haller.—1708–1777.

The most cultivated physician and the greatest naturalist of his age was Albert Haller, of Berne. His advent upon the theatre of action is characterised as the illumination of a meridian sun upon the obscure dawn of day. Haller was of patrician parents, but it was no misfortune to him, as is the rule, and his subsequent career in the face of the temptations besetting wealth affords an illustrious example of the manner in which money may be made subservient to the higher purposes of life. A puny, delicate, rachitic boy, he could not be kept away from books. It is said of him that up to the age of nine years he had read over two thousand biographies. When his father died, his education was committed to a priest who attempted to force his studies in the direction of theology with the intention of making him wear the robes. But Haller loved the teachings of nature better than the wisdom of man, and the time which should have been devoted to clerical studies was spent among the flowers. He was only 15 years old, when he commenced the study of medicine at Tübingen. All the anatomy he could learn here was from dissections of the dog. The fame of Boerhaave and Albinus drew him to Leyden. Here he became such a favorite with his teachers that Albinus would permit him to dissect on one side of the body while he worked on the other. At 19, he graduated and commenced his travels. He was the student of Douglas, in London, in whom he inspired such confidence that he made Haller promise to help him in his investigations into the development of bone. The same restless, knowledge seeking spirit carried him next to Paris, where his enthusiasm is said to have been kindled to such a pitch under the teachings of le Dran and Winslow, that he stole a body from the grave for material upon which to work. He had to leave Paris to escape punishment and next we find him in Basel, at the age of twenty, teaching anatomy to the students. In 1736, he was now 28, he was elected professor of anatomy and surgery at the newly established university of Göttingen. Proud of so early a recognition of his talents, he labored for the success of this institution until students streamed in to the young college from all parts of Europe. He was now teaching anatomy, surgery and botany. A regular chair of physiology had not yet been established. Besides these labors, he kept up his work in natural history, wrote a great number of literary papers and occupied what leisure was still left in composing poetry. At the age of 45 he was so completely broken down that he had to retire from all active duties. We form some idea of his "iron industry, his almost incredible memory, his profound culture in all the branches of human knowledge" by the story which has come down to us that no one of his Göttingen colleagues ever ventured to visit him without a formal preparation upon the theme to be made the subject of conversation. He is said to have written 12,000 reviews! And yet he never left a letter unanswered. According to all testimony, there was never in medicine a laborer so untiring. Rudolphi näively remarks in the preface to his own work on physiology: "If you should ask all the authors of works on physiology, which book they considered the best, it could not be thought strange if each one would reply, his own. But if you should go further and ask each one what book he considered next best, I am convinced that every one without exception would name Haller's. And surely," Rudolphi continues, "what seems to all the second best must be in reality the first."

Besides this, his greatest work, Haller was the author of three distinct bibliographies, of anatomy, surgery and practical medicine, which have been characterised as "monuments of his incredible literary activity, which stand isolated in medical literature, and will remain for all time as inexhaustible sources of information to the medical historian." Colin, in his Comparative Physiology, called Haller "*L'homme des faits, l'homme de l'observation et des experiences; son œuvre est le point de depart de toute la physiologie moderne.* Cruveilhier spoke of it as "full of discoveries." His original investigations were so numerous and so valuable, as to justly entitle him to the place assigned him by posterity as the "Founder of Modern Physiology." The latter part of his life he spent at Berne in the exercise of the highest civic powers in the state, though even here he found leisure to prosecute his favorite scientific and literary pursuits. The sculpture on the pillar of fame in history has chiseled his name beside that of Aristotle and Goethe and Humboldt.

Characteristics of Physiologists.

And what then were the characteristics of these two great physiologists? They were cautious men. Harvey proved his study twenty years before he preached it. Haller made 109 experiments before he published his discovery of the independent irritability of muscle. They were truthful men. The bitter opposition of their contemporaries, the experimentation of all posterity, have never shaken the facts they advanced. They were simple men; in all their tastes and habits; among other things it is recorded of both, they were men of gentle deportment. Above all, they were working men. And if the question were asked as to the influence of the study of physiology on the character of the physician, there could be no more fitting answer than a reference to the lives of men who have drifted into it as a life study because of their natural adaptability to it.

One point more. Physiology offers to the physician a present refuge in time of trial. The vicissitudes of practice, the rancor of rivals, the unceasing combat against prejudice and ignorance and superstition make life a burden at times even where envy marks it a great success. It is in dark hours like these, and who but knows them, that the physician may turn to the study of physiology. No man of the world, no man of other profession than natural science, may ever know or be able to understand the peace, in the way of fresh inspiration for future work, which nature offers at the foot of her altars. The chief reward of every kind of mental work—higher than either wealth or fame—is its effect upon the character. The study of medicine is peculiarly excellent in developing the mental faculties. Having elements in it belonging to both literature and science—the bride and her spouse in modern education—it most happily blends the virtues and balances the faults, pertaining to a purely literary or a purely scientific pursuit.

I should fall short of the high purpose of our convocation, to-night, should I fail to impress upon you clearly the trial which science demands at your hands before she will adorn you with the stamp of her nobility. It is the trial of work, the chief characteristic, as you have seen, in the lives of our eminent men; work with the sacrifice of self; work which is only stimulated to higher efforts by the achievements of others; work with something, at least, of that feeling in the breast of Themistocles—a poor illegitimate boy—Ruler of Athens he became—who was alone sorrowful and distressed amidst the general rejoicing over the great victory at Marathon. And when they asked him why his eyes were red with weeping and why he walked the streets with disheveled hair, he made them that reply which foretold his future success: "It was the trophies of Miltiades that would not let him sleep."

LECTURE II.

THE CONSERVATION OF FORCE.

CONTENTS.

The Alphabet of Science—Indestructibility of Matter—No Matter without Force—Solar Origin of Heat of Coal—Correlation of Forces—Machinery, a Means of Changing Force—Clocks, Water-Wheels, Winds, Windmills and Steam Engines—The Equivalence of the Forces—The Conservatory of Arts and Trades—Motion from Heat—Motion from Electricity—The Electric Light—The Sun as the Source of Power—Source of Solar Force—The Nebular Hypothesis—The Channel of Mt. Pilatus—The Perpetuity of Force—Physiological Force—Excretions, the Products of Combustion—Animal Bodies as Machines—The Force Value of Foods—Physiological, Correlative with Physical Force.

Within the past quarter of a century has been generally promulgated one of those fundamental principles or laws in natural science which, like that of gravitation or of terrestrial revolution, marks a most memorable epoch in its history. What especially distinguishes this law and lifts it to a plane above all other laws of nature, is the fact that it spans, in its giant grasp, every order of existence. It reduces to shape and order the primitive chaos of the universe, governs the movements of the heavenly bodies thus created, generates the various forms of the mighty forces about us, and, while engaged in this stupendous work, concerns itself no less with the insignificant phenomena of life upon our insignificant globe; swinging systems of planets in their spheres, upon the one hand, and, on the other, springing flowers from the bosom of the earth. I need hardly say that this law, which has been announced as the primal law of all science, and which has been characterised by Faraday as the highest law in physical science that our faculties permit us to perceive, is the law of the Conservation and Correlation of Force. That is, it is the law which has demonstrated that force, as well as matter, is indestructible, however much its form may change, and which has proven that all the forces, light, heat, electricity, motion, etc., may be converted, the one into the other, quantity for quantity, in exact equivalents, no force being ever created anew and no force being ever lost.

We shall study this law to-night more especially in its bearing upon human life, and shall try to make it plain that what is known as life, or vital force, is only part of the general store of force in the universe, borrowed for the time being from other physical forces and being continually surrendered again in the various phenomena of life, as in heat, motion, secretion, reproduction, intellection, etc.

Indestructibility of Matter.

It is now more than a century ago that it was known among men of science that matter is indestructible. When we speak of the destruction of matter, we refer simply to the form of the matter. For instance, we say matter is destroyed by fire. But when we come to analyse the products of combustion, we find in the smoke, the gases and the ash precisely the same elements as before. We proceed to weigh these various products in delicate scales to discover only pounds and ounces and grains, just the same as before. Fire has only changed the form. So when we speak of organic matter suffering destruction by decay, we refer again simply to the form. The water, the salts, the gases of decomposition, weigh exactly the same, are in elementary construction, in every particular, just the same as before. Putrefaction has only changed the form.

And so, too, of creation. We justly boast of our manufactured products. But no ingenuity of man has ever succeeded in creating matter anew. *Ex nihilo nihil fit.* Annihilation of matter, creation of matter are alike impossible and unknown.

Now it is discovered that there is

No Matter without Force.

The force may not be always apparent, that is, it is not always in active operation, but we have simply to change the condition of matter to awaken and make manifest its silent force. Force in operation is known as actual force; that which is silent, at rest, so to speak, or latent, is known as potential force. The arrow speeding in its flight or striking its target represents actual force, while the bent bow, unsprung, represents latent or potential force. The force in the bow is stored up muscular force to be set free, it may be at once, or it may be after years. Plants now living contain recently stored latent or potential force, while coal fields are vast magazines of force stored up ages ago.

Solar Origin of Heat.

George Stephenson, the celebrated engineer, long ago conceived the happy idea, as he sat by his hearth, that the light and heat of the burning coal in his grate originally came from the sun. This thought, which seemed at the time to be as visionary as a poet's dream, is now known to be true. Every one knows that coal is a product of vegetable life.

A fresh fracture often reveals upon its surface the outlines of stems and branches and leaves with such distinctness as to enable the botanist to specify the particular plant which has formed the specimen of coal. Vegetation of all kinds develops only under the light and heat of the sun. Vegetable, seeds imbedded in clean sand and moistened with water containing only mineral matters in solution, germinate and develop into plants containing a large amount of starch. The simple process is as follows:

Carbonic Acid Gas. Water. Oxygen. Starch.

$$C_6\,O_{12} + H_{10}\,O_5 - O_{12} = C_6H_{10}O_5.$$

The light and heat of the sun, entering the substance of the plant, dislodge a certain amount of oxygen gas that the atoms of the inorganic compounds may rearrange themselves to form organic matter. Starch is the first organic principle of the plant. The sugar, cellulose and other ingredients are easily developed by the addition or change of equivalents of water. Thus:

Starch. Water. Grape Sugar.

$$C_6H_{10}O_5 + H_2O = C_6H_{12}O_6.$$

Thus, then, is built up the plant, the tree, vast forests of which covered the earth in primeval times to become subsequently submerged and converted into coal. In burning coal we simply release from it the locked up heat of the sun. The heat and light we enjoy to-night came down from the sun thousands of years before man put in his presence upon earth.

No force is ever lost. It may be changed as to its direction or changed as to its character, but in some form or other it perpetually reappears. So all the affections or conditions of matter, heat, light, electricity, chemical affinity, motion, etc., are mutually convertible. Neither can be said, strictly speaking, to be the cause of the other, but either may be converted into the other: "it being an irresistible inference from observed phenomena that a force cannot originate otherwise than by devolution from some preexisting force." It is, therefore, not right to say that any one force is the cause of all the rest. One writer, for instance, claims electricity as the primal cause; another, chemical action; a third, heat; but the true expression of the fact is, that each mode of force is capable of producing the others, and that any one of them can be produced by any other.

Machinery a Means of Changing Force.

We may best exemplify the conversion and correlation of force by the transmutations which take place in various kinds of machinery. In fact, machinery is only a means of effecting change in the form of force. Thus in our clocks, the wheels which sweep the hands around the dial plates are revolved by sinking weights. When the weights reach the floor of the clock the wheels cease to move. In other words, the force of gravity ceases to act. We must first raise the weights, or, in the case of a watch, give tension to the springs, before the wheels will run. This is accomplished in the winding up. The individual who winds the clock simply transfers power from his muscular force and precisely so much as is thus transferred is again surrendered in the ensuing twenty-four hours. The wheel work of the clock, in measuring out time, creates or exhibits, therefore, no new force; it simply distributes a borrowed force over a longer period of time. The borrowed force is that of the muscle, which receives it, in turn, from food containing, latent, the original force from the sun.

We stand in admiration before the majestic revolutions of a gigantic water wheel, whose force is distantly conducted to intricate machinery, constructed to minister to the wants of man. Broad belts here and there take off some of the force for widely different purpose. The antecedent force is gravitation, which causes the fall of the water. The force behind gravitation was that which lifted the water to its higher level. What is this force but the heat of the sun which has raised the vapor of the sea to the clouds, whence it has fallen in rain, to form brooks and rivulets, ever widening streams, the force of whose fall (gravity) may be used in running mills.

The swiftly sailing vessels cleaving the breast of the waters under the resistless force of the wind is no less indebted to the heat of the sun, the unequal distribution of which creates the currents of air and the tides. It is the same force of the wind, produced by precisely the same cause, which, by means of windmills, lifts whole lakes of water from inundated lands.

The most powerful, and the most widely varied, of all our machines, the steam engine, is just as distinctly, though not so directly, driven by the heat of the sun. For, first of all, we make use of artificial heat. This heat is the result of chemical force, the union of oxygen and carbon, *i. e.*, coal, which contains in it, latent, the original heat of the sun. This chemical force produces heat, which is converted into motion, which is, in turn, again converted into heat at the axles of the wheels. A locomotive has therefore been likened to a kind of distilling apparatus, which takes heat into its big retort, the boiler, converts it into motion and reconverts the motion into heat at the axles of the wheels.

The Equivalence of the Forces.

What especially contributed to establish the doctrine of the conservation of force, was not so much the discovery that one force could be converted into another, but that one force, or one form of force, could be converted into another, quantity for quantity, in exact equivalents. Though the constancy of the forces was first formally announced by Grove before the London Institution in 1842, it did not receive general acceptance until Mayer and Helmholtz, of Germany, and more especially Joule, of England, had succeeded in establishing the equivalents of various kinds of force, that is, the amount of one kind, or form of force, necessary to produce a certain amount of another kind of force. The correlation, or convertibility of force, is thus based upon the conclusion that the whole amount of force in the entire universe is always the same. It may change its form continually, but it may never change its total sum. Joule first discovered the equivalent of heat to mechanical force. The quantity of heat sufficient to raise the temperature of a pound of water one degree in temperature would, when properly applied, raise a pound of water 772 feet high. One degree of heat is, therefore, equivalent to the mechanical force represented in an elevation of 772 feet. This constant relation between heat and mechanical force has been confirmed in the most varied manner and the law thus established has proven of the highest importance in practical adaptation to mechanics.

As every form of steam engine is an illustration of the convertibility of heat into motion, it would seem needless to cite further proof, but I may not refrain from mentioning the curious application of the law recorded by Liebig in his article on the Connection and Equivalence of Forces in the case of the

Conservatoire des Arts et des Métiers,

in Paris. In this building, which was formerly a convent, the nave of the church was converted into a museum for industrial products, machines and implements. In its arch, traversing its whole length, appeared a crack, which gradually increased to the width of several inches and permitted the passage of rain and snow. There were, doubtless, not wanting individuals at this time who looked upon this threatened destruction of the building as a sign of Divine vengeance for its desecration. The opening could have been easily closed by stone and lime, but the further yielding of the side walls would not have been thus prevented. The whole building was on the point of being pulled down when a natural philosopher appeared on the scene and proposed a plan which finally saved the building. A number of strong iron rods were firmly fixed at one end to a side wall of the nave and after passing through the opposite wall were provided on the outside with large nuts which were screwed up tightly to the wall. The nuts were now tight, but no force was sufficient to move the walls a line. So then the rods were heated with burning straw, whereupon they extended in length. The nuts were thus removed several inches from the wall and were now again screwed up further on to the thread and tight to the wall. The rods, on cooling, contracted with enormous force and made the side walls approach. By repeating this operation the crack entirely disappeared. The building, with its retaining rods, is still in existence, a monument to the triumph of a natural philosopher over the supposed act of vengeance of an offended Deity.

Even the savages knew how to transform

Motion into Heat

by the friction of two pieces of wood or by striking a flint. A skillful blacksmith can render an iron rod red hot by hammering. The axles of our carriages have to be greased to lessen the heat of friction. In some factories where a surplus of water-power is at hand, this surplus is applied to cause a strong iron plate to revolve swiftly upon another, so that they become strongly heated by the friction. The heat so obtained warms the room and thus is secured a stove without the expense of fuel.

An example of

Motion from Electricity

we have proclaimed from our watch towers every day at noon, or on the occasion of every fire. Electricity is converted into the motion of the hammer which falls upon the bell. This electricity itself is the product of chemical action, that between zinc and acids at work in a few glass cups. Almost any chemical action, as the oxidation of metals, or the burning of combustibles, the combination of oxygen and hydrogen, develops electricity. There is little doubt that the time will soon come when we will be able to realise as electricity the whole of the chemical force, which is active in the combustion of cheap and abundant fuel, such as coal and wood and fat, and thus "secure a mechanical power in every respect superior to its applicability to the steam engine."

Even now we convert

Electricity into Light,

whose brilliance over that from every other artificial source is a promise of the power we shall one day possess in every field of mechanics. Let us trace up the transformations of force now necessary to secure a powerful electric light. First, light, the result of electricity, produced by magnetism, in turn developed by the mechanical force of steam, which force is a transformed chemical force evolved in the combustion of fuel, containing in it, latent, the original light of the sun.

In every case we finally block up at the sun.

The Sun is the Ultimate Source

of all the force manifest upon the earth. With the exception of the tidal force, partly caused by the attraction of the moon and which, though in some isolated cases it is utilised to run a few mills, must, nevertheless, be regarded as the earth's greatest foe, because it is insidiously checking up the velocity of our rotation, with the inevitable effect of finally plunging us into the sun, with this exception, all terrestrial force emanates from the sun. But the sun is so vast, its resources are so enormous, that it can feed our whole planetary system and still irradiate infinite heat into interstellar space. The surface of the sun measures 115,000 millions of square miles and its mass is 350,000 times greater than that of the earth. The amount of heat and light emanating from the sun is sufficient to account for all the force of whatever form, manifest upon the earth. According to the pyrheliometric measurements of Pouillet, three or four equivalents of heat are received upon every square foot of the earth under perpendicular rays of the sun. The amount received daily is equivalent to that engendered in the consumption of five billions tons of stone coal, which is again equal to sixty-six billions horse-power every hour. If the entire quantity of solar heat received in a year were uniformly distributed over the whole surface of the earth, it would suffice to melt a universal layer of ice one hundred feet thick or bring from the freezing to the boiling point an ocean covering the earth to the depth of fifteen miles. In every second of time the sun irradiates into space as much heat as would result from the combustion of eleven thousand six hundred billions of tons of stone coal. We are told as an easily remembered relation, that each portion of the sun's surface, as large as our earth, emits as much heat, per second, as would result from the combustion of a billion tons of coal, whence it is calculated that if its whole mass consisted of coal and could burn right out to the last ton, maintaining till then the present rate of emission, the supply would last five thousand years. The small pencil of rays which the earth intercepts at a distance of ninety-three millions of miles is only the one-twenty-three-hundred-millionth part of all the heat irradiated from the sun. This heat at the surface of the sun is so intense as to volatilise iron and other metals, which we are unable by any known method of application to reduce to a gaseous state upon the earth. The enormous quantity and intensity of heat from the sun can only be fully comprehended by some familiar illustration of its magnitude. As Helmholtz has put it: "Its diameter is so great that if you suppose the earth to be put into the centre of the sun, the sun itself being like a hollow sphere, and the moon going about the earth at its distance from it of 238,000 miles, there would still be a space of more than 200,000 miles around the orbit of the moon, lying all interior to the surface of the sun." The heat and light from such a vast source of power are thus infinitely more than sufficient to account for every form of force upon earth without the necessity of any local genesis.

But under the doctrine of the conservation of force we may not stop at the sun. What then is the

Source and Origin of the Forces in the Sun?

The original signification of physiology, a description of nature, permits us, without too great migration from our proper studies, to consider, for a moment, the workings of nature in its grandest fields, in the construction and movements of the heavenly bodies. I avail myself here, in the main, of the clear and concise description of Helmholtz, in his paper on the Interaction of the Natural Forces, taking the liberty, simply, of condensation and omission to bring the subject within the limits of our time.

A number of singular peculiarities in the structure of our planetary system indicates that it was once a connected mass with a uniform motion of rotation. Without such an assumption, it is impossible to explain why all the planets move in the same direction around the sun, why they all rotate in the same direction around their axes, why the planes of their orbits and those of their satellites and rings all nearly coincide, why all their orbits differ but little from circles, and much besides. From these remaining indications of a former state, astronomers have shaped an hypothesis, regarding the formation of our planetary system, which although from the nature of the case it must ever remain an hypothesis, still in its special traits is so well supported by analogy, that it certainly deserves our attention. No other hypothesis has ever so well explained the facts. It was Kant, first, who, penetrating the fundamental ideas of Newton, seized the theory that the same attractive force of all ponderable matter, which now supports the motion of the planets, must also, in ancient times, have been able to form from matter loosely scattered in space the planetary system. Afterwards, and independent of Kant, Laplace, the great astronomer, laid hold of the same thought and gave it the support of his fame.

The commencement of our planetary system was thus an

Immense Nebulous Mass,

which filled the portion of space now occupied by our system far beyond the limits of Neptune, our most distant planet. Even now we see similar masses in the distant regions of the firmament, as patches of nebulæ and nebulous stars; and within our system, comets, the zodiacal light, the corona of the sun during a total eclipse, exhibit remnants of a nebulous substance, which is so thin that the light of the stars passes through it undiminished and unbent. If we calculâte the density of the mass of our planetary system at the time when it was a nebulous sphere, reaching out to the path of the outmost planet, we find that it would require several cubit miles of such matter to weigh a single grain.

The general attractive force of all matter must, however, impel these masses to approach each other and to condense so that the nebulous sphere became incessantly smaller, by which, according to mechanical laws, a motion of rotation, originally slow, would gradually become quicker and quicker. The enormous centrifugal force thus developed, acting most energetically, of course, upon the equator of the nebulous sphere, would swing off masses from time to time, which, separating from the main mass, would form themselves into single planets, or, similar to the great original sphere, into planets with satellites and rings, until finally the principal mass left condensed itself into the sun. When the nebulous chaos first separated itself from other fixed star masses, it must not only have contained all kinds of matter which was to constitute the future planetary system, but also, in accordance with our new law, the whole store of force with which we have since become acquainted. Then, too, an immense dower of force was bequeathed in the entire or partial arrest of the general attraction of all the particles for each other. When through condensation of the masses, particles came into collision and clung to each other the force of gravity is lost to reappear as heat.

The store of force yet possessed by our system is also equivalent to immense quantities of heat. If our earth, whirling about the sun at the rate of eighteen miles a second, and whirling on its own axis, in our latitude, at the rate of 110 feet a second, were to be suddenly stopped in its orbit, a calamity not to be feared in the present condition of things, by such a shock a quantity of heat would be generated equal to that produced by the combustion of fourteen such earths of solid coal, that is, the earth would be heated to 11,200 degrees centigrade, in other words, it would be instantaneously fused and converted into vapor. When it then fell into the sun, as would of necessity be the case, the quantity of heat developed by the shock would be just 400 times greater still (Helmholtz).

Here, now, we have something of a clue to the mysterious origin of the heat of the sun. From time to time a similar process is repeated upon our earth in the fall upon it of meteors or meteoric stones deflected from their course about the sun. It has been calculated that a velocity of 3,000 feet a second would raise a piece of meteoric iron 1000° C. in temperature, or, in other words, to a vivid red heat. Now the average velocity of meteors is thirty to forty times this amount, and we can thus understand why it is that meteors often burst upon striking the earth with a violent explosion, or are completely fused to vapor, by the resistance of the air, before reaching it at all.

But, it is now generally admitted by physicists and astronomers that the solar heat has had its origin, in the main, almost wholly in fact, in

Processes of Contraction;

and that it is maintained by such processes. In other words, the gravitation of the sun's mass has given birth to all, or very nearly all, the heat which the sun has emitted in the past and will continue to emit to the end of his career as a sun. As, however, the heat resulting from this contraction corresponds to only about twenty million years supply, a period far short of the known age of the earth, the theory has been proposed that an immense store of heat was already present in the original nebular mass. The hypothesis most generally accepted by astronomers at present derives this original heat from the collision of dark bodies circulating in space. But we are now being carried too far away from our special studies in the attempt to follow up the transformations of matter and force in the remotest history of the universe. It is sufficient for our purpose to know that the immense store of force in the sun, like the insignificant store of the earth, was also derived from some antecedent force; and whether this force was the result of meteoric bombardment of the sun, as formerly believed, or of continuing condensation of matter, as now maintained, are questions of no essential difference. The practical result is the conversion of

Gravitation into Heat.

To form even a faint conception of such mighty forces, we are in constant need of some familiar standard. Such a basis for estimation is given by Mayer, in his work on Celestial Dynamics, in the case of the

Gigantic Wooden Channel,

in which tall trunks of trees were allowed to glide down from the steep and lofty sides of Mount Pilatus into the plain below. This channel, which was built about forty years ago by the engineer Rupp, was nine miles in length and was so nearly perpendicular, that the largest trees were shot down it, from the top to the bottom of the mountain, in about two minutes and a half. The momentum possessed by the trees on their escaping at their journey's end was sufficiently great to bury their thicker ends in the ground twenty to twenty-five feet. To prevent the wood getting too hot and bursting into flames, streams of cold water had to be let into the channel in various parts of its course. But this stupendous mechanical process appears infinitely small when compared with the cosmical processes on the sun. It is here the mass of the sun which attracts and, in lieu of the height of Mount Pilatus, we have distances of thousands upon thousands of miles. The amount of heat that would be generated by cosmical falls, is at least nine million times as great.

The Perpetuity of Matter and Force.

Such are the questions that engage us and the conclusions that face us in studying the operations of the Law of the Conservation of Force. "Presented rightly to the mind," I cite from the eloquent peroration of Mr. Tyndall, "the discoveries and generalizations of modern science constitute a poem more sublime than has ever yet been addressed to the intellect and imagination of man. The natural philosopher of to-day may dwell amid conceptions that beggar the visions of Dante and Milton. So great and grand are they, that in the contemplation of them, a certain force of character is requisite to preserve us from bewilderment." All the energies of our earth, mighty as they seem to be, are derived from the small pencil of rays it receives from the sun. Of this store, which represents but the one-twenty-three-hundred-millionth part of all the heat irradiated from the sun, but a small fraction is really stored up in latent force. And in all the lapse of human history, at least, there has been no diminution in the efflux of solar force. "Measured by our largest terrestrial standards such a reservoir is infinite; but it is our privilege to rise above these standards and to regard the sun himself as a speck in infinite extension—a mere drop in the universal sea." We pass out to regions in space where all our planets are invisible and the sun himself is reduced to a point of light. We may pass again, beyond and beyond, to points where the places of each successive survey disappear in the limitless regions of space, boundless, because we no sooner assign a boundary than we must ask, what bounds the boundary. Everywhere and forever is the same force and matter in the midst of incessant change. Creation, annihilation still remain impossible and unknown. Nebulæ may condense into systems and suns, collisions of suns may reproduce nebulæ, our earth, our whole system, nay, our visible firmament might, in the figurative language of the Orient, be indeed rolled up like a scroll and wafted to distant regions of space, but the matter and the force must forever remain the same; *secula seculorum*, the same.

Physiological Force.

When a weight is lifted by the hand it seems a long way off to go to the sun for the muscular force necessary to effect it. Yet the fact is capable of direct proof. All muscular force, all force of whatever character in the body, is directly liberated from the food. We have already seen how the light and heat of the sun become locked up in the plant and all animal life is directly or indirectly dependent upon the life of plants. Either the animal feeds upon vegetables exclusively, as in the case of the herbivon, or it feeds upon the flesh of these animals and thus indirectly upon the plant. "The carbonic acid of the air which is decomposed by the plant, is decomposed solely and exclusively at the expense of the light of the sun. Without the sun the reduction can not take place and an amount of sunlight is consumed exactly equivalent to the molecular work accomplished." The so-called chemical rays of sunlight (blue and violet) have a higher affinity in the green leaves of plants for the carbon of the carbonic acid gas than has oxygen. The carbonic acid gas is thus decomposed, the oxygen is set free and the carbon and the chemical rays of the sun, which thus disappear completely, are locked up in the plant. If the solar rays fall upon a surface of sand, the sand is heated, but the heat is later irradiated into the air, but if these rays fall upon a forest, some of it is retained or invested in the structure of the trees. "A bundle of cotton ignited bursts into flames and yields a definite amount of heat; precisely that amount of heat was abstracted from the sun in order to form that bit of cotton. This is a representative case. Every tree, every plant, every flower, flourishes and blooms by the grace and the bounty of the sun" (Tyndall).

In the bodies of animals, vegetables are burnt up just as coal is burnt up in the furnace of the engine and thus is liberated the force in either case. So much fuel, so much force, in the case of the engine; so much food, so much force, in the case of the animal body. The plant is like the clock wound up but not running. In the animal, the pendulum is swung, the wheels are started and the latent force is set free. The clock runs down. And as surely as the force which moves the clock's hands is derived from the arm which winds the clock, so surely is the force of the muscle derived from the sun.

The great mass of organised matter in both plants and animals consists (aside from water) of carbon compounds; carbon united with oxygen, hydrogen and nitrogen. These compounds are built up in plants from inorganic matters in the earth and air. The carbon is chiefly derived from the carbonic acid gas in the air. The vast magazines of carbon stored away in our inexhaustible mines of coal, extending from the tropics to the poles, were abstracted from an ancient atmospheric ocean far richer in this gas than the air about us now. The remaining ingredients, oxygen, hydrogen and nitrogen, are derived from water and air, and the ammonia and nitrates constantly present in each. Compounds of these simple bodies are constructed in the protoplasm of nature in the same manner as in the laboratory of art. In fact, complex organic substances have been already thus artificially compounded. Wöhler first, in 1828, made urea ($CH_4\,N_2\,O$) from the cyanate of ammonia and a number of organic compounds, allantoin, for instance, and various organic acids have been since artificially constructed.

Excretions, the Products of Combustion.

The essential difference between organic and inorganic compounds lies in the fact that the inorganic compounds are products of oxidation (combustion). They have been already oxidised, these ashes of nature, and admit of no further combustion. Organic compounds, on the other hand, containing little or no oxygen, are still highly oxidisable (combustible). The phenomena of life; that is, the liberation of the latent forces stored up in these compounds; depend upon the oxidation of these compounds. We have as the result of life precisely the same oxidation products (excretions) from these compounds as after their more direct combustion. When an animal or a vegetable body is burned (oxidised), the mass of it is resolved into the gases of combustion. The carbon unites with oxygen to become carbonic acid gas (CO_2), the hydrogen unites with oxygen to form water (H_2O), or with nitrogen to form ammonia (NH_3), while the phosphorus and sulphur (when present) remain with other inorganic matter in the ash. Examination of the ash reveals carbon (not escaped in gas), chlorine, potassium, sodium, calcium, magnesium, iron, etc.; the same elements and principles discovered in the various excretions of the living body.

When the Duke would excite in the mind of Claudio

(Measure for Measure) a contempt of life, he advises him:—

> * * * "Reason thus with life:—
> * * * a breath thou art,
> (Servile to all the skiey influences),
> * * * * *
> For thou exist'st on many a thousand grains
> That issue out of dust."

The plant-cell, then, absorbs from the earth and air these inorganic, oxidised compounds, and under the light and heat of the sun liberates the oxygen and fixes the now deoxidised compounds in their substance; whereas the animal cell absorbs (ingests) the deoxidised compounds and the oxygen with which it burns (oxidises) them, and thus again reduces them to gases and salts for reabsorption by the plants. That is, the earth and air feed the plants, the plants feed the animals, the animals feed the earth and air. This is the great circle of nutrition in nature. The carbon of the carbonic acid gas in the air becomes the carbon of cellulose, starch, sugar, fat, etc., of the plant, which, in turn, furnishes carbon for the albumen in the blood, muscle, brain, etc., of the animal, by which it is again delivered over as carbonic acid to the air, whence it was derived.

The plant-cell fixes in its body as latent force the light and heat of the sun, that the animal cell may set it free in other forms, as in heat, electricity, mechanical work, nerve-force, etc. But that the animal cell may possess this power, it must make constant consumption of oxygen gas. In the body of man, where the liberation of forces meets its highest expression, the consumption of oxygen is immense. A man of average weight inhales, by various avenues, 700–1000 grammes per day, that is 500–700 pounds of oxygen a year. And as the great bulk of his body is composed of material already thoroughly oxidised (two-thirds to three-fourths of it is water), it may be readily seen that all the organic matter of the body would be soon resolved into gases and ash, were it not for the new matter constantly furnished by the food. The new matter thus furnished so nicely balances the loss by oxidation that the body, though in incessant change, may lose nothing of its weight in years. And that the atmosphere may also remain the same under the constant abstraction of oxygen by animal cells, this gas must be as perpetually furnished by the plants. Thus, that the 700–1000 grammes of oxygen, appropriated by each human being in a day, to say nothing of other animals, may be restored to the air, the plant must decompose enough water and carbonic acid gas to make 33–40 lbs. of starch, cellulose, etc., in the same period of time.

Animal Bodies as Machines.

Our bodies come, therefore, to be regarded as machines for the exhibition of various forms of force. As the steam engine liberates in other forms the forces stored up in the fuel, the body sets free in the phenomena of life, the forces stored up in the food. We are, however, unable as yet to construct a machine that may liberate force as perfectly as the human body. Helmholtz has shown that the best steam engine can convert into motion only one-tenth of the force of its fuel, the remaining nine-tenths escaping as heat; whereas the body of man may transform into mechanical work as much as one-fifth of the force of his food, the remaining four-fifths escaping with the unoxidised, that is, the unburnt, compounds in the various excretions.

The Force Value of Foods.

The force of the body being thus directly derived from the food, and the amount of heat being known which the combustion of any article of food outside the body will produce, it is easy to compute the force value of the different kinds of food. Frankland has thus tabulated the force value of foods and has shown, as might have been anticipated, that the most highly combustible articles of food, the fats, stand at the head of the list in the amount of force that may be liberated in their digestion. Thus, half a pound of fat furnishes the same amount of force as one and one-third pounds of flour, one and one-half pounds of sugar, three and one-half pounds of lean beef and five pounds of potatoes. The laboring man gets from his slice of breakfast bacon more work than the retired merchant, professional man or epicure can obtain from a table overloaded with other things.

The appetite comes thus to be recognised as a measure of the capacity for work. A farmer when asked "how he could afford to pay his laborers so well," replied, that "he could not afford to pay them less, as less wages meant less food and less work." Another sat at the table with his men and when he found one of them taking less food he turned him off, as he at once knew that that individual was shirking his work. Longet relates that in 1841, some English and French laborers were engaged in the construction of a railroad from Paris to Rouen. It was soon discovered that the French laborers could accomplish only about two-thirds as much work as the English. It was suspected that this deficiency of force was due to the deficiency of food. The French laborers were thereupon supplied with an equal amount of food and soon were able to accomplish an equal amount of work. "The muscular strength, the intelligence and commercial industry of a people depend upon the proper use and right distribution of its food."

Cost of Fuel and Food.

But if force is more fully set free by the human body than by a machine, the question becomes pertinent: why not employ human beings for mechanical work rather than machinery. The answer is very easy; because of the cost of food in comparison with fuel. A steam engine will work all day at a cost for its fuel of twenty cents; the food of two horses, the equivalent of the machine, costs $2.00; and the food of twenty-four men, required to perform the same work, costs $10.00. Hence, as Donders has shown, the animal body can never successfully compete with the steam engine, and "the worst use to make of a man is to employ him exclusively in mechanical work, a statement which harmonizes with the increased introduction of machinery in our advancing civilization."

If we should allow any humanitarian influence a place at all in this consideration, we should have to remember also that if we divert all the force in the body to mechanical work, there is none left for mental work. The force of the body is of course pretty much a fixed quantity, just as it is for a machine, depending largely upon its original construction, as determined by heredity. We cannot use all the power of a machine for a special purpose, say to saw a log, and have enough left to turn a mill-stone. So with very few exceptions hard muscular workers achieve no eminence in intellectual life. Stallions whose force is to be used in reproduction are kept idle in the stalls.

The body of man is built up of cells (protoplasm), which are, in turn, composed of atoms or molecules, whose arrangement (transmitted by heredity and modified by external conditions) determines the special action or use. Or, as Goethe has put it: "*Nicht allein das angeborene, auch das Erworbene ist der Mensch.*" (Man is not alone what he inherits; he is also what he acquires.) The action of protoplasm, though sometimes apparently, is never really spontaneous. The cells are called into action by stimulus, which, so far as we can trace it, always proceeds from without. The various phenomena of life are principally manifestations of reflex action. In simple bodies (individual masses of protoplasm) the outside stimulus is conveyed from atom to atom, like chemical force in gunpowder, from grain to grain. In complex bodies the stimulus is carried along definite trains (nerve-strands) to special destinations. If a muscle contract, it contracts in obedience to stimulus carried to it by a motor nerve. The stimulus conveyed along the nerve has its development in a nerve-center (ganglion). The stimulus experienced in the nerve-center is in turn derived from a sensitive nerve. The sensitive nerve transmits an impression received upon a sensory surface (skin, mucous membrane, gland, etc.). Even the most complex manifestations of the brain fall under the same category. So-called voluntary movements are only the final responses to impressions made upon the special senses at the time or in the past (memory). The highest expressions of the intellect of man may be resolved into the more perfect transmutations of outside forces by machinery made more perfect by original construction (heredity), or made more perfect by labor, (education).

Thus:

Physiological is Correlative with Physical Force,

or, more literally expressed, is identical with physical force, and, the matter of our bodies being the same, and the forces which operate upon it being the same, as in the inorganic world, the exhibition of life is no more due to an innate principle, a separate essence, a *quid intus*, a something within, than is the registry of time in a clock.

LECTURE III.

THE ORIGIN AND EVOLUTION OF LIFE.

CONTENTS.

Definitions of Physiology—Ancient Definitions of Life—Modern Definitions of Life—Difference between Organic and Inorganic Matter—The Property of Assimilation—Period of Development of Life—The Theory of Evolution—Palæontology—The Cataclysms of Cuvier—The Operation of Existing Causes—The Age of the Earth—The Evolution of Fossil Forms.

Physiology (φυσις, λογος), in our day, has a meaning very different from the old conception of the term. It is no longer a "description of nature" in general, according to its literal origin and primitive significance. The vast collection of facts in natural science, accumulated since physiology first was taught, has been classified in appropriate lists, and relegated to special and separate departments. The range of physiology in ancient times becomes apparent from the titles of the works of the oldest authors. Thus, Aristotle wrote a work entitled *Historia, Partes, Incessus, Motus, Generatioque Animalium; atque Plantarum naturæ brevis descriptio.* Aristotle was the first to use the term όι φυσιολογοι, designating as such, Thales, Anaximenes, Heraclitus, Diogenes, Empedocles and Anaxagoras, philosophers who were engaged in the study of the nature of things, their causes and commencements. Fernel first (1538) limited the term to the nature of man in health. Boerhaave and Haller used it in the sense of the use or actions of the various parts of the body. Synonims of Physiology were the Philosophy of Living Bodies, Dynamology, Organonomia, Zoonomia, Biology. Johannes Müller (1833), "who dealt the death blow to vitalism" in physiology, called it "The Physics of

Organisms," basing it solely upon Anatomy, Chemistry and Physics.

Physiology, in its modern sense, is limited to the phenomena observed only in living things, and though really only more closely allied with subjects not especially endowed with life, it has gradually become disencumbered from necessary consideration of them. Physiology is, in short, biology, the science of life.

What, then, is Life?

A satisfactory definition of life in a few words was a want experienced long before physiology was studied as a separate branch of knowledge. With the ancients this question was easily answered. Life to them was a miracle, a supernatural creation. "Humanity in its infancy, like the infant still in humanity, was satisfied with a word it could not comprehend." Every inexplicable event, from an eclipse to an epidemic disease, was accepted as a miracle, and further inquiry was prevented, if not punished, indeed, as a presumption upon the prerogatives of the gods.

Ancient Definitions of Life.

Or, later, definitions of life were evolved from the revelries of metaphysics. Life, said Thales, of Miletus, emanates from water with every other earthly thing. According to Pythagoras, the principle of life is heat. Alcmeon thought that the principle of life was in the blood, but the soul, a distinct principle, was seated in the brain. The chief ingredient in the manufacture of life for Empedocles was fire, though water, air and earth, all the elements, entered into its composition. It was with fire stolen from heaven that Pygmalion infused the breath of life into his marble statue. Hippocrates, most wise of all, refrained from any definition of life, and counseled the study, not of its causes, but of its manifestations. Plato, the great spiritualist, maintained that the rational soul, an immaterial essence, was located in the brain, the irrational, likewise an essence, in the abdomen. The body is only the theater in which the soul lives, and thinks and acts. Aristotle subdivided the soul to such extent as to localise its parts in every organ, whose functions the special parts direct. The still popular "animation" of the heart, stomach, bowels, liver, spleen and kidneys is the relic of these views. In the reaction which naturally followed this exaltation of the soul, Epicurus, like Democritus before him, renounced the soul entirely with every form of immateriality. The body is only an accidental collocation of atoms, whose aggregation and arrangement explains the different functions. Galen with his pneuma again restored the soul as the principle of life. It was developed in the ventricles of the brain, and lodged in the arteries, the air or pneuma carriers, whence they have their name. But with Galen came again the reinstatement of observation, as recommended by Hippocrates, and the first establishment of experiment. Galen is thus justly looked upon as the father and the founder of scientific physiology. Unfortunately, his example had no followers. "Fireside and writing-desk theories"—easier paths to notoriety—soon supplanted bed-side observations and experimental studies, one after another triumphing in turn, until everything was lost in the succeeding darkness of the middle ages. "The field of physiology illuminated for a moment by the genius of Galen was then enshrouded in twelve centuries of gloom."

After the long night of ignorance and superstition broke the dawn of the day which is still upon us in glimmers of light from the natural sciences. From the still smouldering embers of alchemy and astrology—as Christianity upon the altars of the unknown gods—were fanned the flames of modern chemistry, physics, and the other natural sciences, under the light of which were read new interpretations of the principle of life. Paracelsus, Van Helmont and Sylvius, could see in its most complicated phenomena nothing but effects of combinations in chemistry. Descartes introduced the new science of mechanics. "The body had been an alembic; now it was a machine. The principles of gravity, mechanics and hydrostatics served to explain the phenomena of the senses, the movements of organs, the exercise of all the functions, and even the acts of intelligence" (Longet).

Again, there was reaction toward a vital as distinct from physical force. Haller, who was second only to Harvey, for having revived anew the long neglected studies by direct observation and experiment in lieu of surmise and speculation, discovered the inherent "irritability" in various tissues, a property innate to the tissue itself, and characteristic of living matter.

Modern Definitions of Life.

The definition of life in our own day has been mostly a play upon words. Bichat says "life is the sum total of the functions which resist death." Lawrence declares it to be "an assemblage of all the functions or purposes of organised bodies, and the general result of their exercise." Lewes defines life as "a series of definite and successive changes without destruction of identity." Duges calls it "the special activity of organized bodies," Beclard, "organisation in action," and Spencer, "the coördination of action." Truly, it might be said of all these phrases, they are only idle repetitions of "life is life."

Thus, to define physiology as the science of life, is one thing; but to define life, the subject of which it treats, is another. One might almost say that the definition of life is a rock surrounded with shipwrecked attempts. It is no answer whatever to say that life is a creation.

Such an assertion may satisfy the wants of the emotions, but it will in no way appease the demands of the intellect, trained by cultivation in physical science to entirely ignore unnatural explanations for natural events. Equally empty and evasive in the periphrase that life is the result of all its phenomena.

Difference between Organic and Inorganic Matter.

May we succeed better, perhaps, with the understanding of life by a comparison between matter endowed with it, and that which is not? Automata have been made to simulate every visible manifestation of life. Vaucanson's duck could walk, talk, *i. e.*, utter sounds (Faber's machine could talk), eat, digest food, and even void per anum indigestible residue. Yet this automaton was wholly built up of wheels and springs, retorts and tubes, mechanical and chemical devices, a cunning contrivance to nearly realise the fanciful conception of Frankenstein. In what respect does such a finished piece of mechanism differ from an organism, a really living thing?

It has been said that the activity of an organism is innate, while that of a mechanism is accidental. An animal lives, moves, and has its being of itself, while a machine, steam-engine or watch must be supplied with fuel or wound up before its activity is shown.

But an organism is no more capable of living without food, than a machine of running without fuel. The food is fuel in a literal sense, and it is the combustion of the food in the body of man, as it is the combustion of fuel in the furnace of the engine, that develops the force in either case.

Again, it has been said that activity of some kind or other is essential to the organism, but unessential to the mechanism; that is, if the organism ceases to act, it perishes and is lost, whereas an engine remains an engine, or a watch remains a watch, even though not set in motion for years. But we know many organisms that have ceased to show any signs of life for years and yet still exist as such. Small wheel-like animals, tardigrades, rotifers, etc., may be completely dried up and kept as lifeless particles for years, to be restored with every manifestation of life, swimming as actively as before, on being put again in water. Frogs and fishes, low in the scale, have been frozen hard into inanimate bodies and again thawed into life. Seeds from the tombs of mummies have been made to germinate and bear fruit after the desiccation of a thousand years.

Nor can the much-vaunted power of reproduction be looked upon as a criterion of living things. The power of reproduction is present only at a certain phase of life in all animals and plants, and yet at every period are they none the less alive. Besides, many living things are sterile throughout life, as the workers among bees, the soldiers of ants, hybrids among horses, etc.

Nor, again, may it even be maintained that every living thing is descended from a parent like itself; for many species of animals and plants now upon the earth differ so entirely from ancestral forms as to have been long regarded as entirely different species. A skilled zoologist is required to trace the resemblance between fossil and existent forms.

The Property of Assimilation.

Nevertheless, observes Brücke, who has so clearly established these refutations of long accepted views, we do possess a difference, which enables us to separate living from lifeless matter. Organisms have the property, with which no mechanism of any kind has ever been endowed, of taking up foreign matter and transforming it into their own substance; and the organism grows at the expense of the substance thus acquired. This is the property of assimilation. "It pertains to every organism, so long as it is an organism, and must pertain to every organism, because upon it is based its whole organic life." But if we contrast the growth of an organism with the growth of inorganic matter we may not make this difference so distinct. For, in the first place, we observe that the elements which go to form an organism are not different from those that constitute inorganic matter. The carbon, hydrogen, oxygen and nitrogen of living matter are precisely the same carbon, hydrogen, etc., in the inorganic world. A simple monad, a shapeless mass of protoplasm, scarcely contains as many elements as a piece of common feldspar. That either should increase in size, it must be placed in a medium containing matter like itself, or that may be changed into matter like itself. In the slow evaporation of the solution of a salt, the formation of crystals develops. Each crystal particle grows by addition to its surface. In the growth of an organism the addition is effected from within. So far as growth is concerned the essential difference between the two is merely one of density. Organisms are of soft consistence, hence are penetrable to nutrient matter. Inorganic matter, from its nature, is hard and dense, impenetrable from without. Growth may only take place on its surface, but it is here, as in the organism, always at the expense of the new material. It is true that in the organism the new material is subjected to chemical change, a new arrangement of its atoms resulting from its absorption and assimilation, but this change is due to the fact that carbon, the principal elementary ingredient of organic bodies, has such multitudinous and varied relations with all the other elements. In other words, the various manifestations of life, in its simplest forms at least, admit of explanation on physical grounds alone; and, so far as growth and reproduction are concerned, it is no more necessary to invoke the phantom of a mystic vital force in their comprehension, than in the explanation of the form or formation of a crystal in the inorganic world.

Whatever theory we may adopt as to the nature of life, there is no longer any doubt as to the

Period of its Development upon our Earth,

that is, it is positively known that life did not appear coeval with the dissipation of the chaotic confusion which marks the first epoch in every theory of creation. Ages must have lapsed before the necessary conditions of life could have developed.

Two theories prevail at present in the civilized world regarding the first creation of life; the so-called miraculous and non-miraculous theories. These theories are more euphemistically designated the teleological and mechanical theories; teleological (τελος, end and λογος, discourse) because evincing design, according to human conception of the term; and mechanical in the sense of being explicable by the action of natural laws in continuous operation. The miraculous is the supernatural theory as revealed in the first book of Genesis. Because it has received its finest exposition in our day at the hands of the great English poet, Milton, this theory is often called the Miltonic theory. It is depicted in the Bible with the solemn cadence, the metaphor and poetic imagery, the "inspiration," characteristic of the Orient. In its regular sequence of chaos, darkness, absence of form and life, then light, water, vegetation, aquatic life, land life, and, last of all, man, it is in perfect harmony with the natural theory of creation. But, in its disposition of the earth as the center of the universe, and of man as the center of all life, it is directly opposed to all the facts of astronomy, geology and biology. The earth we know to be but an atom in the illimitable expanse of space and we have reason to consider man but as an accident of conditions upon its surface prevailing at his time.

The non-miraculous is the natural theory of creation. This theory in the first place repudiates every idea of creation in the strict sense of the term. Such a thing as the creation of a new substance is impossible and unknown. The matter of which our earth consists has existed and will exist forever. It may become subject to as many changes in future ages as it has undergone in the past; it may, ultimately, even lose its separate existence and identity by fusion with other globes of matter and return to a former nebulous state, but the matter of its present composition must remain, in essence, forever the same.

> "Dinanzi a me non fur cose create,
> Se non eterne, ed io eterno duro."

As it is imperishable, it may not have been created. In its organic form it may suffer decomposition but, as we have seen, the water, the gases, the "dust," into which it is resolved, is the same matter in its elements as before. It has only changed its form. The smoke and ashes of matter consumed by fire, weigh exactly as much, and are the same elements as before. Creation under the natural theory refers not to substance, but to form.

Facts in the natural sciences, which it is not our province to repeat, enable us to trace back the past history of our earth, through successive changes of form, to a mass of molten matter, irradiating its heat into space, until its exterior was enveloped in a more or less solid crust. The subsequent condensation of steam, into which its water had been forced by heat, let the rain fall upon the surface until it was wholly covered with water. The surging of the molten interior lifted land above the waters in islands, continents and mountain chains. Then, when the heat had been sufficiently reduced, when water was present in quantity, when an atmosphere (though not the air we are breathing now) floated above the waters, then—all the conditions being present—life was developed in its lowest forms, as inevitably as the heat was irradiated, or the steam condensed, or the minerals crystallised into special forms, or as inevitably as any physical law.

The Theory of Evolution.

That higher and higher forms of life were successively developed from lower forms, is now abundantly proven by facts in palæontology, comparative anatomy and embryology, as well as by direct observation of the effects of natural and artificial selection.

Palæontology, the Science of Petrifactions,

or of fossils, furnishes what may be now called indisputable proof of the gradual evolution of higher forms of life. "The organisms buried in the most ancient geological strata must be looked upon as the ancestors from which the rich diversity of forms of the present creation have originated by continued generation and by accommodation to progressive and very different conditions of life" (Carus). The different strata of the earth, successively deposited at different epochs of time, may be thus regarded as so many shelves, each filled with specimens of synchronous creation. Of the vertebrate animals, for example, we encounter first fish, then amphibious animals, then reptiles, birds and mammals.

The explanations offered to account for the existence of fossils on any other theory than that of evolution are very curious. It was believed, for instance, that fossils were models in clay or mineral matter of subsequently improved creations in organic life. According to others, petrifactions resulted from the influence of the stars upon the interior of the earth. "Sports of nature," they were playfully called. Since we have become acquainted with the vast denudations effected by the action of the air and falling and running water, we can readily understand how forms of life become gradually encrusted with sand and mud, and remain entombed for all time, as indestructible as the subjects and objects in Pompeii and Herculaneum while still enveloped in ashes and lava.

Though the animal nature of fossils was recognised by some of the ancient Greek philosophers, notably by Xenophanes, of Colophon, as also by Aristotle, and though even the manner of their petrifaction seems to have been understood by that most versatile genius of the fifteenth century, Leonardo da Vinci, it was not until the beginning of the present century that their regular order of deposit began to be observed, so that laws could be deduced to entitle palæontology to a distinct place amongst the exact sciences. We owe our first definite knowledge of the deposition of these ancient forms of life to the great natural philosopher of France, George Cuvier. This observer discovered that the fossils deposited last, that is, those nearest the surface in undisturbed strata, most closely resembled the forms of life now existing upon earth, whereas those deposited first, in the deeper strata, differed most widely from living forms. Unfortunately, Cuvier was not able from this most suggestive discovery to proclaim the gradational development of forms of life, and thus anticipate for himself and his time the honor of the discovery of the theory of descent. The differences in the forms of life encountered in different strata, he believed to be inherent, and to have been imprinted from their birth. In other words, he believed that each new strata represented an entirely new creation of all the forms of life.

millions of years, rain must have fallen upon its surface to effect the present degree of denudation. The formation of coal and of coral, of stalactites and stalagmites, furnish indisputable evidence of the lapse of ages upon ages of time. "Men are in the habit of measuring the greatness and the wisdom of the universe by the duration and the profit which it promises to their own race; but the past history of the earth already shows what an insignificant moment the duration of the existence of our race upon it constitutes. A Nineveh vessel, a Roman sword awakens in us the conception of gray antiquity. What the museums of Europe show of the remains of Egypt and Assyria we gaze upon with silent astonishment, and despair of being able to carry our thoughts back to a period so remote. Still must the human race have existed for ages and multiplied itself before the pyramids of Nineuch could have been erected. We estimate the duration of human history at 6000 years; but immeasurable as this time may appear to us, what is it in comparison with the time during which the earth carried successive series of rank plants and mighty animals and no men; during which in our neighborhood the amber tree bloomed and dropped its costly gum on the earth and in the sea; when in Siberia, Europe and North America groves of tropical palms flourished; where gigantic lizards, and after them elephants, whose mighty remains we still find buried in the earth, found a home? * * * * And the time during which the earth generated organic beings is again small when we compare it with the ages during which the world was a ball of fused rocks. For the duration of its cooling from 2000° to 200° centigrade, the experiments of Bishop upon basalt show about 350 millions of years necessary. And with regard to the time during which the first nebulous mass condensed into our planetary system our most daring conjectures must cease. The history of man, therefore, is but a short ripple in the ocean of time" (Helmholtz).

It is only necessary to appreciate the great age of the earth to understand the might of the slow and silent changes in perpetual operation, and to realise the truth of the remark that "changes which are rare in time are frequent in eternity."

It was this revalation of the order, instead of disorder, observed in the history of the development of the inorganic world that enabled palæontologists to disclose in fossils the

Gradational Evolution of Forms of Life.

It is only within the past twenty years that proof of this fact has received its highest confirmation in the accumulation of evidence of the existence of man in ages antedating any historical record. It may be stated as now beyond question that "not only man, but, what is more to the purpose, intelligent man, existed at times when the whole physical conformation of the country was totally different from that which characterises it now." And the fact itself that the difference is so slight between the most ancient remains of human forms as yet discovered—the celebrated Neanderthal skull for instance—and the forms now upon the surface of the earth, is most conclusive evidence of the time required to effect any very great change in the physical conformation and constitution of our earth. The horse, which now exists is the same in all essential regards as the horse of the period of time referred to, but is a very different animal from the horse of a much more ancient period. It was the recognition of the eras of time necessary to effect radical changes in the structure of animal forms under the slow agencies of natural selection that forced upon scientists the conviction that no series of sudden catastrophes or convulsions have marked or marred the even course of nature. As Mr. Huxley has remarked: "Catastrophic palæontologists are now practically extinct." It may not be said, indeed, that our record is in all respects complete. When we consider the disturbing elevations and depressions to which all parts of the earth have been repeatedly subjected, the very small extent of surface as yet explored—not the one-thousandth part of the whole—the metamorphic changes which heat has induced in the lowest strata of rock, and when we recall the perishability of intermediate forms, and of all except the hardest parts of all forms, we cease to wonder at the "missing links." Many cf the specimens still preserved are in sadly mutilated state, like the wounded in the broken ranks at the roll call after battle. But the losses are compensated in some degree by the skill of the interpreters. Some of you are doubtless familiar with the story of Zadig in the Romances of Voltaire. He was a youth who had "chiefly studied the properties of plants and animals, and soon acquired a sagacity that made him discover a thousand differences, when other men see nothing but uniformity." The light and long furrows impressed upon the sand between the marks of the paws, revealed to him that the animal escaped was a bitch recently whelped; other side traces told of the hanging ears of a spaniel, and the slighter impression of one of the paws showed that the animal was a little lame. Thus also he was able to divine the height of a runaway horse, the length of his tail, the character of his shoes and bit, in a manner to astound his questioners, and, as has often happened since, under similar circumstances, to render him liable to persecution for sorcery. But how much more incredible and incomprehensible to the unlearned is the more definite and extensive knowledge afforded by a footprint to the palæontologist or comparative anatomist? "Whoso sees merely the print of a cleft foot," wrote Cuvier, "may conclude that the animal which left this impression ruminated, and this conclusion is as certain as any other in physics or morals. This footprint alone yields to him who observes it; the form of the teeth, the form of the jaws, the form of the vertebræ, the forms of all the bones of the legs, of the thighs, of the shoulders and of the pelvis of the animal which has passed by; it is a surer mark than all those of Zadig." A fossil fragment of a lower jaw directly attached to a piece of skull would enable the palæontologist as positively to assert that the animal of which the fragment was part had two occipital condyles with an ossified basi-occipital bone, had also red corpuscles in its blood and breasts to suckle its young.

Thus the excavation of a few fossil bones of the leg in our country completed the line of descent of the horse, the discovery of a couple of small back teeth (of a predatory marsupial) in the Trias formation established the existence of mammals at that early period of time, and the imperfect impression from the Jura of a fossil bird (the archæopteryx) with a lizard's tail confirmed the conjecture previously made that birds were developed from lizards. Thus from a fragment of bone or a tooth, from a feather or a footprint, has been deciphered, as from ancient hieroglyphics, the gradational development of animal life.

For my part, said Mr. Darwin, in speaking of the imperfection of the geological record, for my part, following out Lyell's metaphor, I look at the geological record as a history of the world imperfectly kept and written in a changing dialect; of this history we possess the latest volume alone, relating only to two or three countries. Of this volume, only here and there a short chapter has been preserved, and of each page, only here and there a few lines. Each word of the slowly changing language, more or less different in the successive chapters, may represent the forms of life which are entombed in our consecutive formations and which falsely appear to us to have been abruptly introduced. On this view the difficulties discussed are greatly diminished or even disappear.

LECTURE IV:

THE EVOLUTION OF FORMS OF LIFE.

CONTENTS.

Comparative Anatomy—Of the Eye and the Ear—Order of Development—Jean Lamarck—Wilhelm von Goethe—The Intermaxillary Process—Erasmus Darwin—Anatomical Resemblances—The Hand and its Homologues—Comparative Embryology—Ernst Haeckel—The Rudimentary Organs—Bone Rudiments—Muscle Rudiments—Rudiments from the Digestive System—Other Rudiments—Explanations of Rudiments.

To-day we approach the development of life from the standpoint of

Comparative Anatomy.

The most striking feature in a general survey of the forms of life is their almost infinite diversity. The mind is fairly confused in its attempt to review the vast procession of animated beings in constant defile about us, having nothing more in common, apparently, than motion or growth, reproduction or assimilation, the grosser phenomena of life. Humboldt estimated, many years ago, that there were 56,000 species of plants and 51,700 species of animals. We know now that species are numberless because they are mutable. It is comparative anatomy alone that reveals to us the similarity of structure prevading all these forms, notwithstanding their great diversity in external appearance. By the study of comparative anatomy we are thus enabled to group the forms of life into species, genera and tribes, to single out elements or types of structure from which all the various forms are modeled, however much they vary to superficial inspection, and to trace the points of resemblance to and

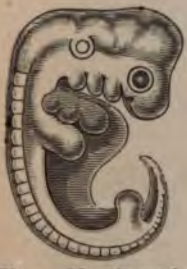

Fig. 1.—Man, iv weeks.

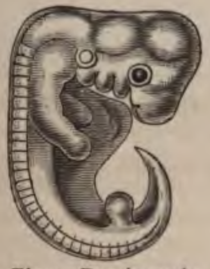

Fig. 2.—Dog, iv weeks.

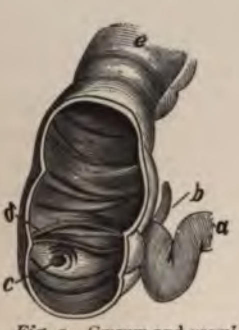

Fig. 5.—Cœcum and vermiform appendix. *a*, small intestine. *e*, large intestine. *d*, ileo-cœcal valve. *c*, orifice, and *b*, termination of vermiform appendix. (p. 80)

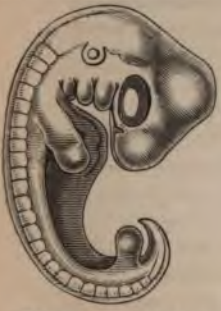

Fig. 3.—Chick, iv days.

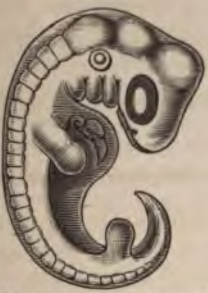

Fig. 4.—Tortoise, iv weeks.

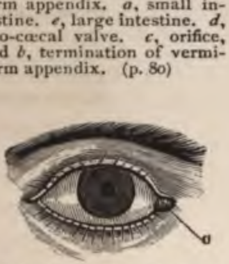

Fig. 6.—Eye. *a*, plica semilunaris, rudimentary nictitating membrane. (p. 80)

THE VERTEBRATE FŒTUS. (p. 74.)

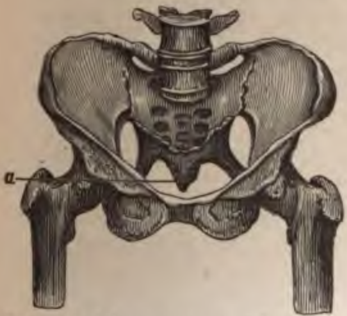

Fig. 7.—Pelvis. *a*, coccyx, rudimentary caudal extremity. (p. 78)

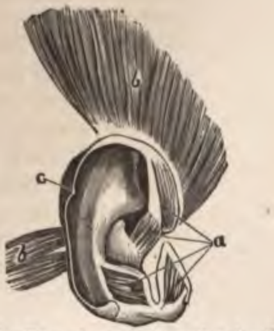

Fig. 8.—Ear. *b*, extrinsic, and *a*, intrinsic (rudimentary) muscles. *c*, position of point of ear turned in. (p. 81)

RUDIMENTARY ORGANS.

protoplasm. In star-fishes the pigment cells are depressed and the cavities filled with gelatinous matter to constitute primitive lenses and to effect the first concentration of light. In articulate animals an optic nerve is coated with pigment sometimes arranged in the form of a pupil. In insects are superadded numerous facets, each a distinct lens to converge the rays of light upon the sensitive nerve filaments beneath. In the lowest vertebrate animal, the lancelet, we start with "a little sack of transparent skin, furnished with a nerve and lined with pigment, but destitute of any other apparatus." As we ascend the scale of vertebrata we successively encounter the more or less developed crystalline lens, the vitreous and aqueous bodies (additional lenses), the retina with rods or cones, or both, and, finally, the accessory apparatus of muscles and lids and lashes, glands for the manufacture of lubricating oil and tears, and tubes to convey away superfluous fluids.

What is true in this way of organs in the body is true of the whole body, that is of the position it occupies in the animal scale. We may observe in the study of comparative anatomy, the

Order of Succession

of different animals in a progressive and uninterrupted chain. In the vertebrate animals, for instance, we see this succession maintained from fishes to amphibia, reptiles, birds and mammals, and from the lower to the higher orders of each class.

Comparative anatomy pays its highest tribute to biology in displaying the general unity of structure in the various forms of life. We owe the first definite exposition of this principle to the distinguished French philosopher,

Jean Lamarck.

In the earliest years of the present century Lamarck published in Paris his Zoological Philosophy, which was according to its title "an exposition of the natural history of animals showing the diversity of their organization and faculties the physical causes which maintain them in life, give rise to the movements they may execute and endow them with sentiment and intelligence." Lamarck first propounded the theory of descent in his Natural History of Invertebrated Animals—1815—1822. In this work he maintained that "the systematic divisions of classes, orders, families, genera and species, as well as their designations, are the arbitrary and artificial productions of man. The kinds or species of organisms are of unequal age, developed one after another and show only a relative and temporary persistence. * * * The differences in the conditions of life have a modifying influence on the organization, the general form and the parts of animals, and so has the use and disuse of organs. In the first beginning, only the very simplest and lowest animals and plants came into existence; those of a more complex organization only at a later period. The cause of the earth's development and that of its organic inhabitants, was continuous, not interrupted by violent revolutions. Life is purely a physical phenomenon. All the phenomena of life depend on mechanical, physical and chemical causes, which are inherent in the nature of matter itself." Lamarck is therefore justly regarded as the originator of the theory of evolution or the doctrine of descent. His views excited, however, but little attention at the time of publication. Lamarck had no idea of the struggle for existence entailed by numbers and the survival of the fittest, the key notes in the comprehension of the doctrine of descent; still for having proposed the theory and backed it with proof from comparative anatomy, Lamarck must always be regarded as the pioneer in this great discovery.

Almost about the same time, the doctrine of unity of structure was occupying the attention of the greatest intellect in Germany,

Wilhelm Wolfgang von Goethe.

We are all fully familiar with the literary achievements of Goethe, whom we are accustomed to regard as second only to Shakespeare as a delineator of human feelings and passions, but few of us are aware that he far surpassed Shakespeare in his deeper and more subtile conceptions of the secrets of nature—the result of higher culture in the physical sciences of his day. In his persistent search after a type of structure in the vegetable world he had already hit upon the leaf—and would have reached the cell, no doubt, had the microscope been in general use—when he directed his attention to the study of animal life. From his investigation into the structure of insects he was able to announce the ring, a succession of which, from the head to the tail, constitutes the whole body, to be the fundamental principle, modified only to form the various parts of the animal. What the leaf was to the plant, was the ring to the insect. So the vertebra is the starting point or ground principle for the vertebrate animal. But for a long time the bones of the cranium confused him. They seemed so entirely different from all other osteological forms in the body "as to transport him," as he said when attempting to deduce them from vertebræ, "into a sort of frenzy." A bleached sheep's skull picked up in the Jewish cemetery at Venice, during one of these perturbed meanderings, revealed to him as in a flash of inspiration the derivation of the cranium from the vertebral bones. Though this view has since undergone much modification, it was of the highest value in its day in concentrating the attention of the scientific world upon the fundamental principles underlying all animal structure. There remains still another discovery of Goethe, worthy of especial mention in this connection, a genuine discovery, which no later developments may ever confute. It is to Goethe that we owe the discovery in man of the so-called mid jawbone,

The Inter-Maxillary Process,

supporting the upper incisor teeth, found constantly in most lower animals in the class of mammals, but up to the time of Goethe, never detected in man. "The strange case now occurred," wrote Goethe, "that the distinction between apes and men was made by ascribing an inter-maxillary bone to the former and none to the latter; but as this part is mainly remarkable because the upper incisor teeth are set in it, it was inconceivable how man should have the incisor teeth and lack the bone." Goethe therefore determined that man must possess the inter-maxillary bone and began his search for it in every skull that came in his way. After examining a great number of skulls he found it at last an independent bone. Every skull possesses it, but as age advances it unites with the superior maxilla so closely that even the line of union, like that of the halves of the frontal bones, is completely lost to view. During the whole of fœtal life it may be readily demonstrated in every case, often too in early infancy it remains still isolated except by membranous connection, but only as the greatest rarity may it be observed in later life. Goethe was so fortunate as to encounter such an unanchylosed specimen and thus could forge another link in the chain of evidence for the theory of descent. "Thus much," said Goethe in summing up his views on animal life, "thus much, then, we have gained, that we may assert without hesitation that all the more perfect organic natures, such as fishes, amphibious animals, birds, mammals, and man at the head of the last, were all formed upon one original type, which only varies more or less in parts, which are none the less permanent, and still daily changes and modifies its form by propagation." No one has so tersely expressed the power of adaptation or adjustment to external circumstances as Goethe when he said "the animal is formed by circumstances for circumstances."

This same thought had, however, already found expression in a different tongue in a different part of the civilized world.

Erasmus Darwin,

the grandfather of the author still living, whose name is now known everywhere, had arrived at the same conclusions without any knowledge of the labors of Goethe or Lamarck. The doctrine of descent "pervaded the air," one might say, on observing its almost simultaneous enunciation in Germany, England and France. Erasmus Darwin published his Zoonomia in 1795, already recognizing at this early period the changing structure of animal life under changing external conditions.

Such is, in brief, the early history of the filiation theory in its relation to comparative anatomy. When we come now to observe for ourselves the

Anatomical Resemblance

between man and the lower animals, we are struck with amazement that their relationship was not noticed long before. The whole structure of the skeleton is glaringly similar among all the vertebrate animals. Confining ourselves to the highest types, we observe such close resemblance between the bones of man and anthropoid apes as to require intimate knowledge of comparative anatomy to declare which is which. The same remark might be made of all the internal organs. The difference between the brain of man and apes is much less, said Vulpian, than between that of apes and the quadrumana just below them. We find, indeed, less difference in bodily structure and mental faculties between higher and lower apes than between higher and lower species or races of man. The refinements of chemistry and spectroscopy have not been able to differentiate the blood of man from that of lower animals. The microscope refuses to note a distinguishing point between the blood corpuscles of man and the dog. Finer evidence even than this, the same medicines, and the same diseases produce the same effects. Post-mortem sections reveal to us the same lesions of structure in apoplexies, phthises, hepatic diseases, brain affections, etc., common to all the higher forms of life. "Many kinds of monkeys," Mr. Darwin relates, "have a strong taste for tea, coffee and spirituous liquors; they will also, as I have myself seen, smoke tobacco with pleasure." The same author quotes from Brehm the assertion, that the natives of northeastern Africa catch the wild baboons by exposing vessels with strong beer, by which they are made drunk. They suffer also the same scourges for these pleasant vices, for monkeykind endure "*katzenjammer*" on the next morning in common with mankind. But Brehm tells the story of an American monkey who after getting drunk on brandy, would never touch it again, and thus was wiser than many men. The taste nerves and the whole nervous system, therefore, is the same in the monkey as in man. Carl Vogt concludes from his numerous investigations that there is no doubt whatever that, according to the fundamental part of the brain, man, belongs to the ape. On comparing, says Gratiolet, a series of human and simian brains, we are immediately struck with the analogy exhibited in the cerebral forms in all these creatures. The convoluted brain of man resembles the smooth brain of the ouistitis in the characteristics of a rudimentary olfactory bulb; a posterior lobe, which entirely covers the cerebellum; a perfectly marked Sylvian fissure, and a posterior cornu in the lateral ventricle of the brain. And he might have added, adds Vogt, the existence of a central or intermediate lobe which occurs in all apes. "Thus there is a cerebral form peculiar to man and ape; and so in the cerebral convolutions, wherever they appear, there is a general unity of arrangement—a plan, the type of which is common to all these creatures" (Gratiolet). "But," Bischoff persists, "there is no time when we may not differentiate the brain of a monkey from that of a man." "True," replies Mr. Darwin, "else a monkey would be a man." The difference is only difference in degree. As long ago observed by Wundt, animals are creatures whose intelligence differs from men only by the degree of development. There exists between men and brutes (mutes is a better word), no wider gulf than is to be found within the animal kingdom itself. All animated organisms form a chain of connected beings without an interval. It is only "an antiquated psychology, with its great variety of mental faculties, which draws here and there lines of demarcation."

Man belongs to the division of vertebrates, the class of mammifera and the order of apes. But it is known that man did not descend from any of the existing anthropoid apes. No naturalist now maintains this view. Man is known to have descended from a catarrhine ape with pointed ears, a hairy skin, a caudal extremity, arboreal in habit, an ancestral form, common to man and to existing apes. Nearly ten years ago, Dr. Barrago Francesco published a work, bearing in Italian the title, "Man made in the image of God, was also made in the image of the ape."

The Hand and its Homologues.

Perhaps no part of the body will furnish a more satisfactory demonstration of the unity of structure, notwithstanding the difference of external form, than the termination of the upper extremity, the hand in man or its homologue in lower animals. If we compare in this way the hand of man with that of the gorilla and orang, with the forepaw of the dog, the flipper of the seal and dolphin, the wing of the bat, the shovel foot of the mole and the forefoot of the duck-bill, we shall find them to be composed of exactly the same bones, arranged in exactly the same order, with exactly the same connections. The breadth and thickness of the thumb in the gorilla, so much approach that of man, that, as Mr. Huxley justly observes, there is more dissimilarity between the hand of the orang, which has one bone more in the carpus, and that of the gorilla, than between the hand of the gorilla and that of man. Indeed, the hand of man, the highest of mammals, more closely resembles the fore extremity of the duck-bill, the lowest of mammals, than any of the intervening types. As with the hand, so it is with every other member or organ in the body, the similarity of fundamental structure betrays the kinship, the inheritance from the common ancestral type

Comparative Embryology.

But, comparative anatomy only sheds its full illumination over the field of biology when its light is turned upon every stage and phase of life. Hitherto it is only adult or mature forms that have been thought worthy of any consideration. In quite récent years undiscovered treasure has been disclosed in embryonic life, a phase of existence almost wholly ignored, or at least studied only by the privileged few. What makes comparative embryology especially profitable in the study of the development of forms of life, is the fact that changes of structure occur in the embryo with such very great rapidity. The transformations of maturer types, which geological ages required to effect under the slow agencies of natural selection, are run through in the fœtus in a few weeks or months. Thus we may observe, at different stages of fœtal life, phases of development and evolution, for whose recognition in mature forms we must appeal to the faulty records of the primæval world. It is in the respect of its completeness, thus, that the evidence furnished by embryology is so much superior to that of palæontology. And for this evidence it may be claimed with equal truth that it has not been "tampered with by the hand of man."

Although the main facts in our present knowledge of embryology had been divulged as long as a century and a half ago by the eminent German naturalist, Caspar Wolff, and although the full history of embryonic development of animals had been exhaustively studied by Pander and Bär within the first quarter of this century, yet it was not until the present decade, our own day, as it were, that we have become familiar, through the labors of

Ernst Haeckel, of Jena,

with the developmental phenomena of fœtal life, and their significance in comparative anatomy. Haeckel conceived the happy idea of placing accurate representations of the fœtus of different animals, including man, in parallel columns that their resemblance, one might almost say, identity of form and structure, should be apparent at a glance. No one may look upon these representations of the fœtus of man, the dog, the chicken and the tortoise, with an unprejudiced eye, and fail to be convinced of their unity of structure. The general conformation, the position of the upper and lower extremities, are the same in every fœtus; the various vesicles of the brain are alike present in each; the organs of the senses and the viscera are similarly located and disposed; and each has a caudal termination projecting between the lower extremities.

Perhaps the most striking feature common to every fœtus is the row of branchial clefts on the under and lateral surface of the neck. The human fœtus presents these fissures as distinctly as every other. But it is only in the fish that these clefts persist to become developed into the gill arches supporting the leaves formed by the ramifying pulmonary vessels, "the fishes ears," properly, its lungs. The gill arches of the human and most other vertebrate fœtus are subsequently absorbed in the formation of the jaw and organ of hearing, but their existence at an early period of embryo life is incomprehensible in any other light than that of construction upon the same fundamental plan. At a still earlier period in the life of the human fœtus, the arteries run in arches to these branchial clefts and some time after the superfluous arches have shriveled away, the branchial clefts still remain as landmarks of their former place. The arch of the aorta, and the arches of the subclavian arteries, are the last relics of the vascular arches of earlier dates.

In the human fœtus, as in that of all vertebrate animals, the heart is at first only a dilatation of the aorta, a simple, spindle-shaped, pulsatile vessel without septa or valves. The human fœtus has also, in common with the rest, a pair of Wolffian bodies, in lieu of kidneys, and its excreta, like the rest, are voided through a cloacum. The convolutions of the brain of the human fœtus at the seventh month nearly exactly correspond to those of the adult baboon. Mr. Huxley makes the remark, that it is only "quite in the later stages of development that the young human being presents marked differences from the young ape, while the latter departs as much from the dog in its developments as man does. Startling as this last assertion may appear to be, it is demonstrably true."

Embryology reveals to us the significance of organs and structures like the Wolffian body and ductus venosus, or urachus, etc., and at the same time reconciles otherwise discordant features in comparative anatomy. The development and formation of the lower extremity may serve as an example. The similarity of structure of the upper extremity among all vertebrate animals has already been mentioned. It is easy to recognize the same bones, in the same order, arrangement and connection, etc. But in the lower extremity this harmony is apparently not observed. Thus, in the leg of the bird, we may observe the femur, below it the tibia, but in place of the tarsus and metatarsus, there is only a single bone to which the phalanges are attached. Here is a gross dissimilarity which strongly militates against the unity of structure. If we turn, however, to the development of the bird in the egg, the dissimilarity is dissipated at once. For we find in the fœtal bird, first the femur, then the tibia, below it two bones to constitute the tarsus, and below these two short, thick bones, and parallel with each other, are three or four long, slender metatarsal bones to which are appended the phalanges. The upper tarsal bone subsequently coalesces with the femur, the lower with the tibia, the metatarsal coalesce with each other to form one, and thus is the leg, as well as the wing of the bird, shown to be constructed from the same fundamental form. "In short, the history of development," as Oscar Schmidt observes, "which describes the gradual formation of the organism, is at every step a beacon to comparative anatomy."

While we are considering the lower extremity, I may call your attention to the fact that Carl Vogt has shown the foot of the gorilla to be more anthopoid than that of any other ape, and the foot of the negro more ape-like than that of the white man. The bones of the tarsus in the gorilla exactly resemble those in the negro; the ape has the same broad, flat, low heel; the large toe is thicker and longer than in the other apes, but the toes, on the whole, are longer, more moveable and the thumb more opposable. "The posterior limbs of the gorilla," says Huxley, "terminate in a real foot, with a moveable great toe. It is a prehensile foot, if you like, but no hand, a foot which differs from that of man, not in any fundamental character, but in mere proportions, in the degree of mobility and in the secondary arrangement of its parts."

The Rudimentary Organs.

Comparative anatomy, again, furnishes a lucid interpretation of the significance of those obscure structures in the body known as the rudimentary organs. As animals became subjected to different external conditions in the varying history of the earth, new organs originated from time to time, or what was most frequent, simple structures became more and more perfected until entirely different varieties had been formed. These peculiarities of structure were, of course, continually transmitted by heredity. But as the surrounding conditions continued to change, the adjustment or adaptation to these conditions, necessary to secure the existence and propagation of the species, would lead to the gradual sacrifice or reduction of organs, or parts, until at last they would be present in a body, if present at all, in atrophied or merely rudimentary form. Such rudiments or traces of structures which continue to be highly developed among lower animals, everywhere abound in the body of man. Indeed, no system of organs in the body of man is free from structures thus reduced by disuse, and like examples are encountered throughout the animal and vegetable kingdom.

The wings of animals which have lost the power of flight are examples of rudimentary organs. In the ostrich, the emeu and cassowary, the legs have gradually become enormously developed, because flight was unnecessary on account of the absence of beasts of prey, consequently the wings have become gradually reduced by disuse.

The atrophied lung of serpents and lizards and the aborted ovary of birds are also examples of rudimentary organs. The slender length of the body of the snake leaving no room for the pair of lungs to which it is entitled, the one undergoes atrophy and the other compensates for its loss by its elongation. So the right ovary is aborted in birds as a superfluous encumbrance in weight. Teeth which never cut through to appear, as those in the embryo of the whale and ox, eyes which do not see, as those in moles and underground mice, cave beetles and crabs, etc., the hind leg bones of whales and boas, which never develop, are additional examples of rudimentary organs.

Bone Rudiments.

When we come to the body of man, we encounter, as has been said, rudimentary structures in every system of organs. Perhaps the most striking example in the bony skeleton is the coccyx, the rudimentary tail. The individual bones of the coccyx are each but traces of whole vertebræ as they are composed of the defective central bone, without any of the characteristic processes. Occasional monstrosities exhibit the coccyx of unusual length. "It is in monstrosities," it has been said, "that Nature reveals her secrets." A distinct rudimentary structure is sometimes found at the lower extremity of the humerus. It is a small hook-like process of bone projecting downwards towards the inner condyle, with which it is sometimes connected by a band of fibrous ligament. It corresponds to the supra-condyloid foramen of feline animals, transmitting the brachial artery and often the median nerve and protecting them from compression during the contraction of muscles in seizing and holding prey. This rudimentary process of bone, though present in only about one per cent., of recent skeletons, is much more commonly met in ancient specimens; thus Dupont found thirty per cent. of humeri perforated in the caves of the valley of the Lesse, belonging to the Reindeer period.

Muscle Rudiments.

The muscular system is peculiarly rich in rudimentary structures. Remnants of the panniculus carnosus, the great surface muscle of the horse, are met in the platysma myoides, the surface muscle of the neck, and in fasciculi in the axillæ and near the scapulæ, as also in the superficial muscles of the scalp so markedly developed still in some people. The extrinsic muscles of the ear are typical rudimentary structures. These muscles are highly developed among wild animals and give the external ear its quick motion in different directions to catch the faintest sounds. As the animals became domesticated and the danger lessened, the muscles gradually atrophied. Many dogs and rabbits, the latter the most timid of all animals, have thus in security lost the power to "prick up" the ears, which have become in time long and loose appendages. Though careful dissection will reveal traces of these muscles in man, their power is lost except in rare cases. The intrinsic muscles of the ear have become more rudimentary still, and the ability to move parts of the auricle upon each other is entirely lost. The rudimentary muscles about the coccyx, the relics of the powerful muscles of the tail in the lower animals, are worthy of mention in concluding the examples from the muscular system.

Rudiments from the Digestive System.

The digestive system furnishes two notable rudimentary structures. One is the wisdom tooth. On account of the softer character of the food in civilized life, less mastication is required, consequently the length of the jaws is being reduced and room is scarcely afforded for all the last molar teeth. The very last is the last to appear and the first to fall. It has now but two fangs, whereas in ancient skeletons it possesses three, the number normal to molar teeth. It is the most caducous of all teeth and is slowly becoming rudimentary. The absence and not the presence therefore of the last molar tooth will have to be regarded as the sign of "wisdom." The other example from the digestive system is the vermiform appendix. The preparation of the food has become such a science as to limit the period of digestion in the body. It might, indeed, be said that the food is largely digested by the cuisine before its ingestion into the body. Consequently much of the capacity of the alimentary canal has become superfluous. The head of the large intestine, which forms almost an additional stomach in the gramnivora, and is three times the length of the whole body in the marsupial koala, is very much reduced in the carnivora, whose food contains but little indigestible matter, and is greatly reduced in the omnivora, as in man. The vermiform appendix is the shriveled remnant of the great cœcal receptaculum of the lower animals. In the orang-outang it is still a long convoluted tube, but in man it is reduced to the size of a quill three or four inches in length, mostly blocked with mucus. It is often entirely absent.

Other Rudiments.

From the nervous system the most striking rudimentary organ is the filum terminale of the spinal cord, the continuation downwards of the envelops of the cord to the extremity of the coccyx, the relic of the prolonged cord of the lower animals.

The short hairs over the whole surface of the body and the lanugo or wool of the fœtus over the whole surface, except the palms of the hands and soles of the feet, where it is absent in most of the lower animals, are clearly rudiments of the universal hairy coat of these animals. Occasionally a 'reversion' is encountered in the birth of an Esau with a hairy coat.

The eye and the ear each possess a rudimentary structure of curious interest. At the nasal angle of each eye is a small, semi-lunar fold of mucous membrane, the plica semilunaris, which is clearly a rudiment of the nictitating membrane, the third or inner eye-lid in mammals, birds and reptiles. In these animals the nictitating membrane is furnished with a muscle to secure its extension across the entire globe of the eye, in protection of the retina from too great light. Sufficient protection is afforded in man by the more highly developed lashes, lids and iris, and the nictitating membrane has become reduced to an insignificant fragment.

At a point about at the junction of the upper and middle third of the helix of the external ear there may be commonly seen a small blunt point projecting towards the antihelix. Mr. Darwin had his attention directed to this projection by a celebrated English sculptor, and he does not hesitate to interpret it as the "point of the ear" turned in, the vestige of formerly pointed ears in the primal races of man. "In many monkeys," he says, "which do not stand as high in the order as baboons and some species of macacus, the upper portion of the ear is slightly pointed and the margin is not at all folded inwards; but if the margin were to be thus folded, a slight point would necessarily project inward and probably a little outward." Whether this point be so regarded or not, it is pretty generally accepted that the whole external ear, the auricle, having become an immobile shell, hence useless, should be considered as a true rudimentary structure. When all its involutions are filled with wax so as to make its internal aspect a plane surface, or when it is entirely removed, as by accident or operation, the sense of hearing is in no way impaired.

Explanations of Rudiments.

The explanations offered to account for these rudimentary structures in man on any other theory than that of inheritance from a common type and reduction by disuse, are as irrational and ridiculous as those to account for the existence of fossils, and serve simply to show "the embarrassment and distress which their presence has occasioned." It was claimed, for instance, that they were furnished to animals having no use for them to sustain the general plan of creation, or for the sake of symmetry, "just as doctors in the army and navy are made to wear small and useless swords to be in keeping with the officers of the line." But the endowment of the highest animals in the scale with organs which are not only useless, but sometimes absolutely injurious (deaths have occurred from impaction of the vermiform appendix with fruit-seeds and stones), would notseem to be in keeping with a very high design or order of creation. This explanation, therefore, is sufficiently ridiculous, but another offered by an eminent physiologist reaches the very climax of absurdity. It is claimed for these rudimentary organs that they serve to excrete matter that is useless or injurious to the system!

Mr. Lyell says, in his Principles of Geology, that he asked Lamarck in the year 1867, when he was in his 84th year, by what facts and reasonings he had been led to entertain his views, "and he told me that he owed his convictions to the lectures of Geoffroy St. Hilaire, to which he had listened in the early part of this century at Paris. That great zoologist, he said, never lost an opportunity, when he spoke of the rudimentary organs found in so many animals, of pointing out their bearing on the theory of transmutation. According to him, they were clearly the relics of parts which had been serviceable in some remote ancestor and had been reduced in size by disuse, and he rejected the idea as puerile that useless organs had been created for the sake of uniformity of plan." In truth, there is absolutely no scientific explanation for these rudimentary structures other than that of inheritance from a common ancestral form and gradual suppression by disuse, because of subjection to conditions, in which they are no longer of avail.

We have dwelt at length upon the most marked examples of these strange traces, without having by any means exhausted the list, because of their peculiar significance in the interpretation of the development of life. What the germ is to the future, is the relic to the past. Rudiments are like the blocks of ancient temples incorporated into the modern edifices which have taken their place. But they differ from them in being of no use. They are fragments of the crumbling columns of antiquity.

No testimony is more convincing of man s place in nature than that so speakingly furnished by these rudimentary structures. For, as Mr. Darwin has eloquently expressed it, (I take the liberty to interpolate a single line), by them we see that man with all his noble qualities, with sympathy that feels for the most abject, with benevolence which extends not only to his fellow-man, but to the humblest living thing on earth, with an imagination that outrivals and mocks for expression his marvelous gift of speech, with a God-like intellect which has penetrated to the structure and movements of the heavenly bodies—man, with all these exalted powers—still bears indelible, in every organ of his frame, the stamp of his lowly birth.

LECTURE V.

THE EVOLUTION OF FORMS OF LIFE.

CONTENTS.

The Law of Inheritability—Transmission of Acquired Defects—Homochronous Transmission—Atavism—The Physics of Reproduction—Adaptation to External Conditions—Difficulty of Classification—Artificial Selection—The Struggle for Existence—Natural Selection—Protective Colors—Warning Colors—Sexual Selection—Complications in Natural Selection—Preservation of the Individual and of the Race—General Summary.

In concluding our consideration of the evolution of life we have to-day to study the forces or laws which preserve, perfect and diversify its forms. I desire to state, at the start, that though I shall quote from very many authorities, I am indebted for many of the facts which I shall present you to-day, to the publications of Darwin, and for most of them to the *Natürliche Schöpfung's-geschichte* (History of Creation) of Haeckel, a work so complete and comprehensive, as to have elicited from Mr. Darwin the statement, in the preface to his Descent of Man, "If this work had appeared before my essay had been written, I should probably never have completed it." I am led to present you this aspect of the subject simply to complete the evidence for evolution with its most important proof.

The overshadowing law which insures the perpetuity of form is that of

Inheritability.

That "like begets like" is a proverb in every language. The law of inheritance is so universally recognized and acknowledged as to be accepted as a matter of course. It is the breach and not the observance of the law which makes it the subject of comment. The birth of a child with webbed or supernumerary fingers or toes calls up the history of the remote ancestry in its explanation. The cohesion of the family, which is the safeguard of the state and nation, rests upon the acceptance of the principle of heredity. The law of heredity, if we may be allowed to coin the word, secures to the offspring not only the reproduction of the general form of the parent, but also the exact repetition of every physical and mental feature, characteristic of the parent. There were families in Rome which received from the shape of the nose or lips the titles of the *nasones*, *labeones*, *buccones*, etc. Aquiline noses are still transmitted among the posterity of the Bourbons. The Hapsburg (Austria) lip is a peculiarity worthy of mention in this connection. The Prussian kings are noted for their stature. Obesity, color, temperament, longevity, are all strictly transmitted by heredity. Vices of conformation, deformities, diseases, are alike reproduced in the offspring; moles, freckles, tumors, appear in the offspring in exactly the same spots as in the parents. The ancestral history is carefully examined by the physician in establishing his diagnosis of disease. Affections of the respiratory organs, *e. g.*, tuberculosis; of the glands, scrofula; of the nervous system, epilepsy, are especially liable to be propagated in the offspring. Traits of mind are transmitted with equal fidelity. The family of Miltiades furnished heroes, of Pericles politicians. In the family of Bach there were no less than twenty-two musicians. For a generation the name of Graefe was venerated in medicine in Berlin, and in Boston generations of Warrens have been distinguished physicians. So for generations the Rothschilds have been renowned for a special talent in the acquisition of wealth. The horrible cruelties of the Borgias are counterbalanced in some degree, to the credit of Italy, by the refinement and culture of the Florentine Medici.

It is hardly necessary to state that the law of transmission holds with equal force throughout the animal and vegetable kingdoms. Albinoes, *i. e.*, animals devoid of color, have been propagated as a separate species among rabbits and mice, as well as among men. Paraguay is noted for a special race of hornless oxen, bred from a bull born in 1770 without horns. The harmless character of the animal made it the subject of special selection in breeding, until a whole race was thus obtained. The well-known case of the otter sheep in our own country is a good illustration of the force of heredity. A Massachusetts farmer discovered one day among his flock an individual sheep "with a surprisingly long body and short and crooked legs." It occurred to the farmer that this development would be advantageous in rendering leaping impossible and thus checking depredations upon a neighbor's property. He forthwith bred from this individual with the desired result, and his neighbors following his example, the sheep of Massachusetts soon became noted for their staid decorum and profound respect for others' lands.

Transmission of Acquired Defects.

Even acquired defects are sometimes transmitted. Thus Brown-Séquard produced epilepsy in some guinea-pigs by injuring certain parts of their brains, and this artifically-induced epilepsy appeared spontaneously in all the offspring of the diseased animals. Haeckel states that a race of tailless dogs was once propagated by persistently cutting off the tails of both sexes of the dog for several generations. The same author narrates that a few years ago, on an estate near Jena, a bull had his tail wrenched off by the careless slamming of a stable door, and "all the calves begotten of this bull were born without a tail."

Homochronous Transmission.

So strong is the force of heredity, that diseases and defects are not only transmitted, but they are transmitted homochronously, that is, to appear in the offspring at the same age in which they were manifested in the parents. Diseases of the lungs, liver and brain occur in the child at the same period of life as in the parent before it.

Atavism.

But under the laws of heredity the offspring may resemble not so much its parents as its grandparents, or ancestry even more remote. This is the phenomenon of atavism, as it is called. How many peculiarities or eccentricities might we not be able to explain, if we could only sum up all the atoms of being that have come down to us from the bodies of our ancestors in regular line. Oliver Wendell Holmes bases several of the best characters in his novels upon the influence of heredity as far back as can be traced. We observe this phenomenon of atavism in the everyday history of some of the lower animals and plants. The planarian worms, for instance, as well as the ferns and mosses, beget forms entirely different from themselves, and it is only in the offspring of these different forms that the image of the first parents is reproduced. This alternation of generation was first remarked by the poet Chamisso, during his voyage around the world in 1819, in the case of the salpæ, small transparent structures, which float like particles of glass on the surface of the sea. In studying the habits and life history of these animals, Chamisso observed that the parent form, which has an eye of crescent or horseshoe-shape, produces offspring with cone-shaped eyes, but in the offspring of the offspring, the grand-children, so to speak, the original eye of horseshoe-shape reappears. Among other animals a still greater number of alternations manifests. The sea buoys, for instance, skip over three generations, and plant lice ten or twelve, before the original form reappears. Strange as this alternation of form seems at first, it is really not more strange than the different phases of development at different ages in the life of every animal and plant, and it is in this light, therefore, of successive phases of development, that we may regard these various alternative forms. We shall have later explanation for the fact so often observed in man, and even more frequently among the lower animals, that individuals are occasionally born which reproduce in form and character some ancient ancestor, or a type so remote as to have become almost extinct. Horses, for instance, occasionally show such reversions to the zebra or quagga in stripes across the shoulders or along the spinal column, and puppies and heifers are sometimes born which revert in form to types long extinct.

Thus, then, is evidenced the force of heredity. It appears at first a great and incomprehensible mystery, "the mystery of mysteries" once it was called. The exact reproduction of form and feature, vice and virtue, disease and deformity from structures—the sperm and germ cells—beyond the power of vision with the naked eye, would seem a problem beyond the limits of human analysis. "If the naturalist," said Virchow, "cared to follow the custom of historians and metaphysicians in clothing phenomena, which are in their way unique, with the hollow pomp of ponderous and sounding words, here would be his opportunity."

The Physics of Reproduction.

But a close observation of the method of reproduction among the lowest forms of life reveals an entirely material process, cognizable to the human mind. That is, it is not necessary in its comprehension to take refuge under a "miracle." The process of reproduction is a growth beyond the natural limit of size. In the amœba, for instance, a simple, irregular, gelatinous, mass of protoplasm, reproduction is effected by the separation from the parent of a protruded particle of protoplasm, containing atoms or molecules of structure exactly like the main mass. The reproduction or proliferation of cells in a more complex body is the same process of separation, mostly by division, of part of the protoplasm from the rest. In the highest animal, man, the offspring, the new body, is developed from cells originally derived from each parent. The ovum is as much a part of the maternal, and the spermatozoids of the paternal, organism, as the eye or any other organ, and the entire body of the child is only an aggregate of cells multiplied and differentiated from the simple cells of the ovum and spermatozoid. The child must resemble its parent because it is of its parent a part. It must resemble it just as a piece of coal detached from a mass must resemble the original mass. "The child, strictly speaking, does not grow into the man, but includes germs, derived from its parents, which slowly and successively become developed and form the man." Some of these germs, however, may have descended from an ancestor more remote, and lain dormant in the immediate parent, to become developed, under conditions, inexplicable as yet, only in the child. The phenomenon of reversion, or atavism, as it is technically called, thus ceases to be mysterious. We are informed by those who have made the size of molecules or ultimate atoms the subject of special study, that the minute ovum ($\frac{1}{140}$–$\frac{1}{120}$ of an inch diameter), may contain as many as five thousand billions gemmules. Mr. Sorby states that the number of molecules in the germinal vesicle (granting that this constituent of the ovum is the only essential structure) of the mammalian ovum, is such that if one molecule were to be lost in every second of time, the whole would not be exhausted in seventeen years. Surely here are sufficient particles, as Mr. Thompson puts it, "for all the requirements of the most exacting biologist." In the reproduction of man the gemmules from both parents blend to produce the child. The question then is not; does the child resemble its parent; but which parent does it resemble most? Said Goethe:

> "Von Vater habe ich die Statur, des Lebens ernstes Führen;
> Von Mütterchen die Frohnatur und Lust zu fabuliren."
>
> (From my father is my stature and earnestness of mien;
> From my mother is my joyousness and love of romance keen.)

The force or law, therefore, which secures the perpetuation of forms of life is the force or law of heredity.

We take up now the force or law which produces their variation. This force is that of

Adaptation or Adjustment

to the surrounding conditions, as effected in slight degree, comparatively speaking, by artificial, and in high degree, through the inconceivable ages of the past, by natural selection.

The proofs of the evolution of forms of life, and their variation from each other, based upon the action of artificial and natural selection, are the most convincing of all. From an historical standpoint, they are also the most interesting, as having been the means of securing the adoption of the theory of descent. If we had observed the proper chronological order in exhibiting the facts bearing upon this subject, according to the period of their disclosure, we should have first discussed the action of artificial and natural selection. Lamarck had propounded the theory of evolution, it is true, but his views were regarded as visionary, until proofs were advanced by a later observer, establishing it almost beyond dispute. It is almost unnecessary to state at this stage of general information on this subject, that the name of this later observer is

Charles Robert Darwin.

The conclusions reached by the investigations of Mr. Darwin mark an epoch in biology as distinct as those of Galileo in astronomy, or of Newton in physics. Like these most distinguished men, Darwin disclosed not a single discovery or isolated fact, but a great underlying principle, more far-reaching, however, in its conclusions and influential in its effects in relation to the position and prospects of mankind, than any preceding revelation in the history of science. The train of thought and study which led to these conclusions, he has himself described in a letter to Haeckel, October 8, 1864, from which is the following extract: "But for some years I could not conceive how each form became so excellently adapted to its habits of life. I then began systematically to study domestic productions, and after a time saw clearly that man's selective power was the most important agent. I was prepared, from having studied the habits of animals, to appreciate the struggle for existence, and my work in geology gave me some idea of the lapse of past time. Therefore, when I happened to read 'Malthus on Population,' the idea of natural selection flashed upon me."

"Some few, whose lamp shone brighter have been led
From cause to cause to nature's secret head
And found that one fixed principle must be." Dryden.

Difficulty of Classification.

Darwin had hitherto always entertained the view, in common with all naturalists, that all species of animals were separately and independently created, and were consequently immutable in form. But, to say nothing of any other objection to this view, there remained always the insurmountable difficulty and disagreement as to classification. If species were separate and immutable, classification should have been simple and easy. Special features should have readily marked special varieties. The truth was, however, that no two zoologists or botanists agreed in their divisions. We might take as an example one of the commonest European plants, the Hieracium. Some 300 species of this plant were recognized in Germany, but the botanist Fries only admitted 106, Koch but 52, and others only 20. The same difference is met with in the case of the brambles. One botanist claims 100 different species, another 50, and a third groups them all into 5 or 6. In zoology there is as much disagreement. Thus Bechstein distinguishes 367 species of German birds, Reichenbach 379, Mayer and Wolff 406, while Brehm is able to find special characteristics for no less than 900 species. From such gross disparities in classification, it is plain to see that the specific differences assumed must have been largely arbitrary. On the theory of adjustment or adaptation to different surrounding conditions, the varieties of species are easily understood. The habits of life determine the species, and as these habits must change with the continual changes of the external conditions, the mutations of form, "the species," are limitless.

Artificial Selection.

It was the radical changes that man was able to effect in the domesticated animals and plants which gave Mr. Darwin the clue through the labyrinth of the different species. It might be said that we make new species ourselves every day in the cultivation, *i. e.* domestication, of wild animals and plants. We cripple the wings of ducks and fowls, and reduce to rudiments the ear muscles of rabbits and dogs, by simply removing them to places of security. Captivity nearly entirely arrests reproduction in elephants, bears and monkeys, or changes its whole character. The common ring snake, for instance, lays eggs which are not hatched out for three weeks, but if the snake be confined in a cage it does not lay eggs at all, but retains them in the body until development is complete. The very radical change from an oviparous to a viviparous animal is thus artificially produced. A gardner can produce any colored flower almost at will, alter the leaf or stem, dwarf or develop any peculiarity, by changing the external conditions.

Perhaps the pigeon-breeders make the most abundant and most striking experiments in the modification of form. The art of piegon-breeding is said to be very ancient. The Egyptians engaged in it 3000 years before Christ, and the Romans in the days of the Emperors had already commenced to record the pedigree of certain species, as the Arabs that of their horses, or aristocrats among men that of themselves. The court of Abder Khan in Asia, possessed in the year 1600 more than 20,000 pigeons. Inter-breeding and cross-breeding, subjection to different kinds of food, to different climates, to the multitudious differences embraced under the general term surrounding conditions, have, in the course of centuries, produced more than 150 varieties of pigeons, each one of which is so distinct from the other as to have been regarded as a separate species. Among the most marked varieties or species, we may mention the fan-tailed pigeon, in which the number of tail feathers has been increased from ten or twelve, to thirty or forty, the pouter which is endowed with an enormous crop distensible with air, pigeons with periwigs, or with peculiar, often grotesque transformations of the beak and feet, pigeons with singular habits, as carriers, or, most remarkable of all, as tumblers.

The alterations thus artificially effected may extend even to the skeleton, so that the shape or number of its most essential bones may be modified in a high degree. Thus John Sebright, a celebrated London pigeon fancier, absolutely maintained that he could produce in pigeons any variety of external form in one year, and any change in the bones in five years. And yet all these varieties, thus artificially or naturally produced, are now known to be descended from the primary wild blue rock pigeon. Chickens have been produced by artificial selection with beaks so short as to be incapable of fracturing and escaping from the shell.

The same deviations of form have been noticed in all the domesticated animals. The numerous varieties or species of rabbits are all derived from the common gray rabbit, the various species of horse from the zebra or quagga; in short, all domesticated animals, and plants may be now readily traced back to primitive types, to which they naturally revert again, if allowed to run or grow wild.

Having observed thus the radical changes of form which man is able to produce, Mr. Darwin undertook to discover some force or cause in nature which might effect the same changes. Here it was that the thought "flashed" upon him, after a perusal of Malthus' work, of the

Struggle for Existence

entailed by numbers, and the survival of the individual or individuals most favored in some peculiarity, best adapted to the surrounding conditions.

The explanation of the varieties in the forms of life, by means of natural causes, hinges upon the really appalling numbers of each species produced. Linnaeus calculated that if an annual plant produced only two seeds (and there is not one which produces so few) it would yield in twenty years a million of individuals. Darwin has shown us of elephants, which are the slowest of all animals to increase, that in 750 years, the descendants of a single pair would amount to nineteen millions of individuals, that is, supposing that every elephant, during its period of fertility (from the 30th to the 90th year), produced only three pairs of young, and survived itself to its hundredth year. If we go down much lower in the scale of animal life, go down to the microscopic infusoria, we find there numbers which absolutely daze us with their magnitude. Thus, Davaine has calculated that a single bacterium particle would, in the course of twenty-four hours, become the parent of 4096 such particles, in forty-eight hours, to over 16,700 such particles, and between the sixtieth and sixty-second hours, their numbers attain to one to seventy-one trillions. The swiftness of manifestation and virulence of expression of the contagious diseases, supposed to depend upon the presence of such particles in the blood, corresponds thus to the marvelous fecundity of the parent germs. If each spore of one species only of the higher fungi germinated and reproduced its parent, the children would, in the first generation, and in the course of a very few days, form a carpet all over the earth. The increase in the number of human beings—without any hinderance—would double the total every twenty-five years. In every century the whole number would increase sixteen fold. "The population of the United States alone would require, unchecked, but 650 years to cover the whole terraqueous globe so thickly, that four men would have to stand on each square yard of surface."

But even this number of births conveys only a faint idea of the numbers of ova, which never develop at all. Every joint of the tape-worm, for instance, contains thousands of eggs, which, fortunately for mankind, fail to find conditions for development. The number of ova in the human being is no less marvelous. The recent investigations of Sappey, respecting the number of ova developed and undeveloped in the human female, show that they exist, at the period of full adolescence, to the number of nearly seven hundred thousand. Even the more temperate estimate of Henle puts the original number of ova at not less than 36,000 for each ovary.

Millions, billions, trillions of living eggs are lost in animal life; here and there one is born: and of the millions born, here and there one survives. Among the survivors, competition begins at once for the limited means of subsistence. "Every organism struggles from the commencement of its life with a host of enemies. It struggles against animals which feed on it, for which it is the natural food; it struggles against animals of prey and parasites, it struggles against all kinds of inorganic influences, against heat and cold, against the weather, and above all, and most bitterly of all, against organisms most like itself." Whichever individual among animals and plants has some advantage, will be the individual to live, thrive, and propagate its kind. This constitutes what is known as

Natural Selection.

Here comes, for instance, a summer of unusual drought. Thousands of plants perish for want of water; a few happen to have hairy leaves. The hairs on the leaves are hygroscopic. They furnish a larger surface for the absorption of water, so the hairy plants survive the drought, and propagate their kind. Next summer, most of the plants have hairy leaves. Island insects are wingless, or have wings reduced to almost rudimentary state, while the same species on continents have fully developed wings. Wings are a great disadvantage to island insects, because, in soaring aloft, they are swept out to sea and drown. The insects having the wings least developed are, on islands, the favored of nature to survive and propagate their kind. Natural causes thus easily explain the perfect adaptation of structure to conditions without resort to supernatural design.

Protective Colors.

Another example of natural selection is the coloring of the various animals. Some of these colors are distinctly protective. These animals resemble in hue surrounding inanimate objects. Arctic animals, bears, etc., are white like the ice and snow. In summer, when the snow vanishes, they too change color to resemble the gray or black earth. Desert animals, foxes, gazelles, lions, are sandy or fawn-colored. The birds and insects of the tropical forests are green; butterflies are variegated like the flowers; fishes, molluscs, etc., are colorless, or are scarcely distinguished in the sea. Through the crystalline bodies of many fishes and pelagic animals, the words on a printed page may be distinctly read. Reptiles are spotted and striped and scaled like the bark of trees, or reeds, or leafy soil upon which they crawl. These colors conceal the animals from their foes, or enable them to creep unobserved upon their prey, and the individual whose color most nearly resembles his surroundings is the favored of nature to survive and propagate his kind.

Warning Colors.

Other colors, Mr. Wallace has shown us, are warning signals. Certain butterflies and frogs are large and vividly colored. They fly slowly. It is to their advantage to be seen, because they are unfit for food, their juices having a disgusting odor and taste to birds and beasts of prey. Bees and wasps, stinging animals, are often thus distinctly colored to their safety. Mr. Belt tells us that in Nicaragua, there is a frog which is very abundant, which hops about in the day time, which never hides himself, and which is gorgeously colored with red and blue. Frogs are usually green, brown, or earth-colored, feed mostly at night, and are all eaten by snakes and birds. Mr. Belt was convinced, therefore, that this colored frog was uneatable. He took one home and threw it to his ducks and fowls; "but all refused to touch it, except one young duck, which took the frog into its mouth, but dropped it directly, and went about jerking its head as if trying to get rid of something nasty."

Sexual Selection.

Natural selection again comes into play in the difference that exists between the two sexes of all animals. In nearly all cases, the male animal is the larger and more beautiful. It has weapons of offense, tusks, spurs, antlers, teeth, etc.; and of defense, manes to protect the vessels of the neck, skin coverings, etc., in its combats with rivals to secure possession of the female. Locked skeletons of stags are sometimes found in the depth of forests, so many monuments of such battle-fields. The choice of the female falls upon "the most vigorous, defiant, and mettlesome male," and these peculiarities are transmitted to the offspring, or she selects the male endowed with the richest ornaments in plumage, or hue, or is attracted to the most melodious voice, or sound, as in the case of singing birds, crickets, locusts, etc. Prof. Weismann has recently shown that fresh water fleas are brilliantly colored with patches of scarlet and blue as charms for the opposite sex, and that the masks with staring eyes upon the feeble caterpillar's back are "startling" or "terrifying" colors (*schreckfarben*) "that he may enjoy the privileges so usually gained by the ass in the lion's skin." The choice in pairing resulting from the exhibition of these attractions, offered by the courting sex, constitutes what is technically styled sexual selection. We have no time to fully consider the multiform manifestations of sexual selection. You may recall, perhaps, the curious example mentioned by Tom Moore, in his "Loves of the Angels":

> "For well I know the luster shed
> From cherub wings when proudliest spread,
> Was in its nature lambent, pure
> And innocent, as is the light
> The glow-worm hangs out to allure
> Her mate to her queen bower at night."

The rattle of the rattlesnake is also such a call, and not a means of "striking terror," and thus causing its natural food to escape. What an idiotic idea, this last, that an animal should chase away its own food!

It need scarcely be said that all these actions of natural and sexual selections are just as marked in man as in the lower animals. The male captured the female, *vi et armis*, in the middle ages, just as now in savage life. The strongest won. Nearly all the more modern duels concern the possession of an individual among the fair sex. Charm of face and form, of voice and dress, are just as potent in man as in the lower animals. The top-knots and hirsute appendages of the monkey find their analogues in the tonsorial decorations of man. The female bower-bird is no less attracted by the decorations in the way of shells and feathers and colored stones, with which the male bestrews his nest, than is the female of man by a solid bank account, and a three-story front. But there are, in continual operation among the sexes, other higher influences than mere personal attractions, superiorities of mind and character, the conjunctions of which secure to the human race a tendency towards gradual perfection.

Complications in Natural Selection.

The laws of natural selection do not always work, however, in such plain and simple channels. The most complicated conditions and relations sometimes manifest, rendering the tracing of the action of natural selection exceedingly difficult.

Thus, there are small coral islands, whose inhabitants live almost entirely upon the fruit of a species of palm. The fructification of this palm is exclusively effected by insects, which, in feeding upon the flower, bring the pollen grains into contact with the ova. The existence of these useful insects is endangered by insect-eating birds, which are, in turn, pursued by birds of prey. The birds of prey, however, often succumb to the attack of a small parasitical mite, which develops in millons in their feathers. This small dangerous parasite again may be killed by parasitical moulds. So moulds, birds of prey and insects, favor the prosperity of the palm, and consequently of man; while the parasite, insect-eating birds, etc., put them both in danger of extermination. I cite another case almost literally as given by Haeckel. Paraguay is noted for the fact that it contains no wild cattle of any kind. All the countries around Paraguay abound in wild cattle, but there are none in this country but the domesticated cattle. This is due to the fact that there is an insect in Paraguay which lays its eggs in the umbilical cord of the young animals, and finally destroys the animal altogether. If some animal should arise which should prey upon this insect, wild cattle would be again seen on the plains of Paraguay. As these animals would consume some of the fauna and flora of the country, it is easy to see how its botany might be entirely changed, and in the course of this change, the human population would have to alter.

Mr. Darwin's graphic description of the relation between cats and red clover is always quoted in this connection.

The red clover of England, which forms the very best fodder for cattle, requires the visit of humming bees to obtain the formation of seeds. These insects, while sucking the honey from the bottom of the flower, bring the pollen in contact with the stigma, and thus cause the fructification of the flower, which never takes place without it. Red clover which is not visited by humming bees, does not yield a single seed. Now the number of bees is determined by the number of their enemies, the most destructive of which are the field mice. The more the field mice predominate, the less the clover is fructified. The number of field mice again depends upon the number of their enemies, which here, as everywhere, are chiefly cats. Hence, in the number of villages and towns where many cats are kept there are plenty of bees and plenty of red clover.

Now, as the cattle which feed on the red clover furnish the best roast beef in the world, and as it has been conclusively established that superiority of food determines, in great degree, superiority of body and mind, and hence superiority among nations, it is an easy inference to ascribe this superiority, with Carl Vogt, to the influence of the cats which kill the mice, which kill the bees, etc.; much in the order of the house that Jack built. Mr. Huxley, indeed, is unwilling to stop here, as he traces back the chain of causes to those who cherish cats, the elderly unmarried ladies, to whom due homage should be paid for having secured the wealth and prosperity of the great English nation.

A striking example of a radical change effected in plant life by a complicated natural selection is related by Francis Darwin, in his account of the analogies between animals and plants. The bright colors and sweet smells of flowers are, as is now well known, only allurements held out to insects to entice them to carry the fertilising pollen from one flower to another. But there is a wild cabbage-like plant in Kerguelen's land, which alone of the enormous order of the Cruciferæ, is fertilised by the wind. The change in the life history of this plant, which makes it such an exception, depends upon the fact that the insects in Kerguelen's land are wingless, and are therefore bad distributors of pollen. The insects are wingless, because the winged insects have been blown out to sea and drowned. "Thus the pollen of the cabbage has to learn to fly, because the insects will not fly for it."

I quote one further simpler instance of the action of natural selection, because it contains in itself alone the explanation of the action of natural selection in its widest sense.

Some sailors once let loose upon an isolated uninhabited island in the Pacific Ocean a couple (male and female) of pigs. They had an excess of these animals on board, and they turned them out to breed, perchance, for future shipwrecked mariners. The pigs found upon the island an abundance of food, and no enemies. They bred with characteristic fecundity, until the island fairly swarmed with pigs. Subsequently, other sailors put upon the island a couple of dogs. The pigs became the food for the dogs. The dogs multiplied, and the pigs decreased. Finally all the pigs were destroyed, and then, of course, starvation killed the dogs. But during the long periods of superabundance, abundance, and want of food, various modifications ensued in the forms of both animals, making at different times, species very different from those first introduced.

Preservation of the Individual and of the Race.

Here operated upon this isolated island in the Pacific Ocean the two great causes, everywhere at work, one of which insures the perpetuity of form, at least for a long time, while the other insures its mutation. Of these two great causes, one is the instinct which secures the preservation of the species, viz., that of reproduction and the other is the instinct which secures the preservation of the individual, viz., hunger.

So said Schiller long ago:

> Einstweilen bis den Bau der Welt;
> Philosophie zusammenhält,
> Erhält sich ihr Getriebe,
> Durch Hunger und durch Liebe.

Which I have ventured to translate very liberally:

> "Until the earth is all explained,
> Without call on power above,
> Its workings still will be sustained
> By Hunger and by Love."

I present you, thus, in this series of lectures, the barest outlines of the state of existing knowledge concerning the origin and evolution of life, as explained by natural causes. We have considered the subject from the standpoints of palæontology, comparative anatomy, and natural selection only. Of these fields, we have had time to take only bird's-eye views. The proofs offered by philology, the study of languages, and chorography, the geographical distribution of animals, are no less clear and convincing. But these studies are entirely out of our special province. I refer you to the now familiar works of Mr. Darwin, of Mr. Wallace—whose discoveries really forced upon Mr. Darwin the publication of his own views, prematurely, as he then believed—of Haeckel, Schleicher, Geiger, Steinthal, and the recent epitome by Oscar Schmidt, for a full and complete statement of all the evidence. Evidence which may now be likened to an arch composed of many pieces, with palæontology and comparative anatomy as foundation stones at either end, and natural selection as the key-stone in its center.

I do not know how I may better close this part of our subject, now, than by repeating, with very slight modification, the recapitulation of Mr. Darwin at the close of his first and greatest work, the "Origin of Species." It is to his genius that we owe the whole elaboration and proof of the "Theory of Descent," as first advanced by Lamarck in 1809, as it is to his marvelous collection of facts, his clearness of statement, and his candor, that is due its general adóption in every field of science to-day:

It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing in the bushes, insects flitting among the flowers, and worms crawling upon the bosom of the great mother earth. It is interesting to contemplate all these things, and to reflect that these elaborately constructed forms, so different from each other, yet so dependent upon each other, have all been produced by laws continually acting around us. The laws of growth and reproduction; a ratio of increase so high as to lead to a struggle for life, as a consequence to natural selection, and the slow but certain improvement of forms. Thus, from the war of nature, from famine, and from death, the most exalted object which we are capable of conceiving, namely, the production of the higher animals, directly and inevitably follows. There is a grandeur in this view of life, with its several powers, having been originally breathed by the Creator into a few forms, or into one; and in that, whilst this planet has gone cycling on, according to a fixed law of gravity—from so simple a beginning—endless forms, most beautiful, most varied, and most wonderful, have been, and are being evolved.

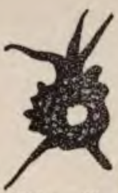

Fig. 9.—The Amœba. (p. 114)

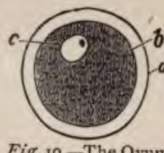

Fig. 10.—The Ovum, a typical cell. *a*, cell wall. *b*, cell contents or protoplasm. *c*, nucleus and nucleolus. (pp. 109-113)

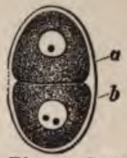

Fig. 11.—Segmentation of the cell. *a*, cell wall. *b*, subdivided cell showing division of nucleolus. (p. 144)

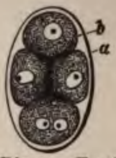

Fig. 12.—Further process of segmentation. *a*, cell wall. *b*, subdivided cells, the lowest of which shows a subdivided nucleus.

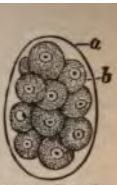

Fig. 13.—Continuing segmentation. *a*, cell wall. *b*, subdivided cells.

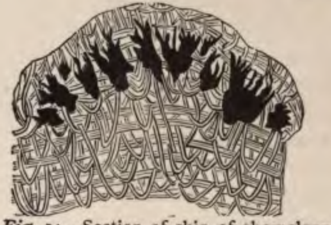

Fig. 14.—Section of skin of chameleon showing pigment cells in retracted (active) state. (p. 117)

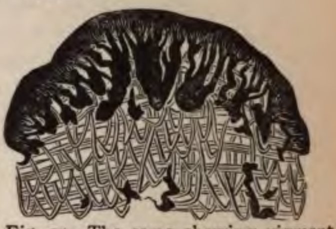

Fig. 15.—The same showing pigment cells in protruded (relaxed) state. (p. 117)

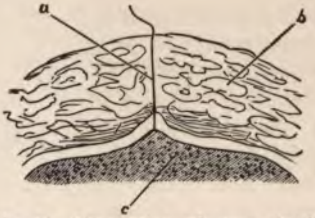

Fig. 16.—Penetration of ovum (without wall) by the spermatozoid. *a*, spermatozoid. *b*, enveloping mucus. *c*, yolk or protoplasm. (p. 124)

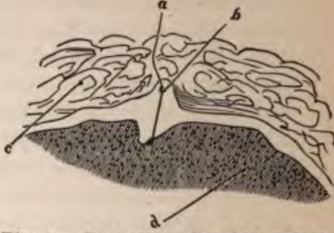

Fig. 17.—The same. Further process of penetration. *a*, spermatozoid. *b*, space in mucus left by retreating yolk. *c*, mucus. *d*, yolk. (p. 124)

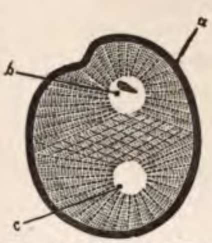

Fig. 18.—The impregnated ovum. *a*, zona pellucida (wall). *b*, sperm nucleus. *c*, nucleus of the ovum. (p. 125)

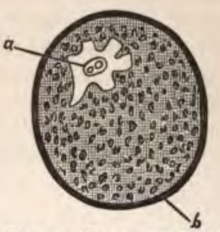

Fig. 19.—The impregnated ovum. *a*, the nucleus resulting from the fusion of the sperm and germ nucleus. *b*, the cell wall. (p. 125)

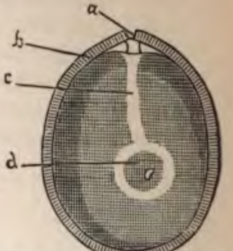

Fig. 20.—The ovum at full maturity. *a*, the micropyle. *b*, the zona pellucida (wall) showing the pore canals (striæ). *c*, the seminal cord. *d*, the germinal vesicle (nucleus of the ovum). (p. 125)

THE CELL AND ITS REPRODUCTION.

LECTURE VI.

PROTOPLASM AND ITS PROPERTIES.

CONTENTS.

The History of Histology—The Invention and Use of the Microscope—The Discovery and Doctrine of The Cell—Derivation and Import of The Cell—The Cell Wall—The Nucleus and Nucleolus—The Cell Contents or Protoplasm—The Amœba—The Properties of Protoplasm—Motion—The Color Changes of the Chameleon—Ciliary Motion—Motion of Other Cells—Molecular Motion—Molecular Changes in the Ovum—Parthenogenesis—Motion as the Essence of Reproduction

We have already seen that different machinery or apparatus is required to effect the various changes of matter and force. We convert chemical force or affinity into galvanism in galvanic cups, magnetism into electricity with iron bars and wires, heat into motion with boilers, cylinders and pistons, etc. That physical may be converted into physiological force there is requisite animal or vegetable matter. In our day, we name this matter or apparatus protoplasm. In complicated arrangement we say the protoplasm constitutes an organism. In the study of physiology we are engaged with the construction of the organism (instrument) which sets the force free, with the mode of action by which it is changed to other forms, and with the various forms under which it reappears.

As there can be no force without matter, there can be no knowledge of action without knowledge of construction.

Our knowledge of the

Construction of the Body

from an historical standpoint naturally falls under two divisions, that acquired before the discovery of the microscope and that acquired since.

The older anatomists and physiologists made us acquainted with everything that could be seen with the naked eye. They described the position and relations of all the organs of the body, defined what we now consider the grosser characteristics of the various tissues and established their general properties. The older anatomists and physiologists drew what we might call the general outlines of all the structures of the body, and with a fidelity which is the highest tribute to their diligence and skill. We read with astonishment the accurate descriptions of Vesalius and Fallopius, of Sœmmering and Bichat, and with admiration the ingenious experiments of Harvey and De Graaf. But the older anatomists and physiologists could not penetrate to the minute construction of the tissues. Histology in the true sense of the term, was a sealed and unopened volume. It was only with the invention of the microscope, more especially with its perfection, that such studies became possible.

The Invention and Use of the Microscope.

The honor of this invention is claimed by the French, the Italians and the Dutch. The truth is, however, that lenses were in use, as such, in ancient times. Aristophanes informs us that globules of glass, known as "burning spheres," were sold by the grocers of Athens. It is hardly possible to imagine that the magnifying power of these spheres could have escaped observation; indeed, we read in Seneca among the "Natural Questions" the following statement in proof. "However small and obscure the writing may be, it appears larger and clearer when viewed through a globule of glass filled with water." So-called "water microscopes," consisting simply of a drop of water attached to the end of a brass wire, were still in common use at the beginning of the 17th century. We have evidence of the ancient use of lenses for magnification in the engraving of characters and letters too small to be visible to the naked eye. We would be hardly prepared to admit that vision was keener centuries ago than now, so that we must believe the eye to have been aided with the lens. Thus Cicero speaks of an Iliad of Homer small enough to have been enclosed in a nutshell, and Pliny mentions that Myrmecides "executed in ivory a square figure which a fly covered with its wings." In fact, veritable lenses have been exhumed from Nineveh and Herculaneum.

The microscope, thus, like every other invention, was in no sense a sudden discovery. It reached from time to time a process of development, to then fall into oblivion for years, or for centuries, and be again revived with improvements to give it new impulse in its gradual evolution.

The first individual to give the microscope permanent place among the acquisitions to the study of nature was Zacharias Janssens, a celebrated optician in Holland (1590). As every discovery in every field of science sooner or later comes to be utilised in the study of medicine, it is not surprising to learn that scarcely 25 years had elapsed before Italian and Dutch anatomists (Malpighi and Leeuwenhoek, 1628–1723), were busy with the microscope in the study of the human body. Though the instruments then in use were exceedingly clumsy and defective, it was with their aid that the most remarkable phenomena in nature were disclosed. The last link in the chain of evidence establishing the circulation of the blood was only completed with the discovery of the blood corpuscles and capillary net work by Malpighi; whose name is still transmitted with histological elements in the kidneys and spleen; and the essential element of the semen—to select only the most striking examples—the spermatozoids were first described by Leeuwenhoek, to whom they had been shown by one of his students, Von Hamm, in 1677.

But the revelations of the microscope, at this period in its history, were, as Frey remarks, "more in keeping with the curiosity loving spirit of the times, than with any definite principle or basis of investigation." Penetration to fundamental structure was still impossible, until the study of histology had received fresh impetus in steps towards the perfection of the microscope, taken first by Dutch and German opticians, Van Deyl and Fraunhofer, in the first decade of the present century. The simple lenses of Malpighi and Leeuwenhoek were now speedily duplicated many times, combinations of different lenses, of different kinds of glass, were soon arranged to obviate aberrations of sphericity and chromatism, and "the clumsy and deceptive implement of the last century was transformed into the elegant and accurate instrument of the present day."

The Discovery and Doctrine of The Cell.

Now, then, for the first time, was rendered possible a penetration to the minute construction of the various tissues. A host of observers were soon engaged in histological study, Müller, Purkinje, Wagner, Valentin, Henle, among the pioneers, and one distinguished above all the rest, "not only on account of his own researches, but also on account of his collocation and arrangement of the discoveries of others, and his deductions thence of general laws, which are to be regarded as the foundations of modern histology" (Tizzoni). The "cell doctrine," as established by C. Th. Schwann (1838), marks the first great epoch in the modern science of histology.

According to this doctrine, as subsequently elaborated more especially by Reichert, Kölliker and Virchow, every tissue and organ of every living thing, plant or animal, is built up of an aggregate of cells, or the products of cells. An organ, the whole organism, is an union of cells, just as a state or association is an assemblage of individuals. "The greatest discovery of the microscope is not, as might at first appear, the revelation of a new world of microscopic life; it is the discovery of the simple, elementary structure of the human body, and of every organised body in nature; it is the astonishing discovery that every living thing, from man to the invisible insect, from the oak to the infusoria, however different their apparent natures, are constructed upon one plan, from one and the same elementary form" (Ranke).

Shape and Size of Cells.

A typical cell is a spheroidal body, consisting of an envelop (or cell wall), of so-called cell contents (protoplasm, bioplasm, cytoplasm, sarcode, etc.), including a smaller eccentrically situated spheroidal mass, the nucleus, which in turn includes one or more still smaller particles, nucleoli.

Such a cell is the ovum, or primordial cell, from which every organised body develops. The various parts of the ovum have, however, been dignified with special names. Thus the translucent wall is the zona pellucida, the contents form the yolk, the nucleus is called the germinal vesicle, and the nucleolus is the germinal spot. The ovum differs from all other cells in the body of man in being visible to the naked eye. It is the largest cell in the body, measuring $\frac{1}{120}$ of an inch (0.21 mm.) in diameter. Hence, in describing the size of cells, the ovum is put at one extreme, while at the other is placed the red blood corpuscle, with a diameter of $\frac{1}{3500}$ of an inch (0.0077 mm). Cells vary in size between these extremes. There is full as great variety in shape. Fat cells are rounded, liver cells polygonal, epithelial cells flat or cylindrical, muscle cells fusiform, connective tissue cells filiform, while bone cells, with their radiating canaliculi, and nerve cells, with their numerous poles and bright nuclei, present very peculiar, stellate or even fantastic shapes.

The whole body is thus reduced to cells of definite size and shape. We obtain, thus, the ultimate elements of organisation. "The cell theory in physiology corresponds to the atom theory in physics, but cells have the advantage over atoms, of being visible and available" (Küss).

The question now arises which of the constituents of the cell, the wall, the contents, the nucleus, or the nucleolus, is the most essential element?

Derivation and Import of the Term.

It should be remarked first that the term "cell" has now a very different significance from its first use. The discovery of Schwann in histology was really based upon the discovery of Schleiden in botany, that sections of young plants under the microscope presented the appearance of the cells of the honeycomb. Schwann observed that epithelial cells present the same appearance, hence, the title of his work, the *Uebereinstimmung*, etc., the similarity or identity in construction of animals and plants, and hence, the term cells. The first intimation of the cellular structure of animal tissue was that of Johannes Müller, who showed that the chorda dorsalis of the fish consists of closely apposed cells with peculiar walls. Müller also first distinguished nuclei in the analogous cells of the chorda dorsalis of the frog. Besides the interest which attaches to this structure as the primitive vertebral column, the chorda dorsalis has also the additional historical interest of having been the tissue in which "the cell" was discovered.

If the tail of a dead tad-pole, after having been for 24 hours in water, be cut through at its point of origin and the chorda dorsalis expressed by gentle pressure from the head downwards, suitable particles of it may be examined under the microscope (best with a 6 per cent. solution of common salt). The cells appear of irregular polygonal form, those from the middle of the chord larger, those from the periphery smaller (Gescheidlen). We have now the picture first seen by Schwann. The likeness to the cells of the honeycomb or to vegetable cells is exact. It was a subsequent elaboration of this disclosure at the hands of a number of observers, the discovery that all the organs and tissues are constructed upon the same plan, so that the cell in modern histology means more than mere form or shape; it means the ground plan, the origin and individuality, the ultimate anatomical element, the chemical laboratory, and the physical and physiological centre in which all the phenomena of life are evolved.

The Cell Wall.

As to the relative importance of the various constituents of the cell, it is known (Bergmann, Bischoff, Kölliker) that the embryonal stage of certain animals exhibits cells composed of nucleated contents entirely deprived of a wall. Moreover there are animals, whose whole life is comprised within the narrow circle of a single cell, consisting simply of a homogeneous mass of contractile substance, without either nucleus or wall. Again, there are forms of life, consisting of multiple cells or aggregations of matter, sponges, radiolariæ, etc., devoid of wall and nucleus. So Max Schultze and Lionel Beale regard the wall as an addition, rather than as a necessary constituent of the cell. According to Schultze, the subsequent formation of the cell wall indicates a limitation in the life of the cell, *i. e.*, it is a sign of decrepitude, while Beale regards the wall as a product of the cell, the formed material, in distinction to the forming, or germinal matter, the protoplasm. Kölliker looks upon the cell wall as the sign rather of full development and maturity. The cell wall, more dense and firm than the remaining constituents, is the protecting envelop of the more delicate structure within, and at the same time regulates diffusion between its contents and circumambient media.

Diffusion is effected through the cell wall, when homogeneous in structure, by simple absorption or osmosis, but is more directly effected in some cases through minute canals, which may be seen in transparent cells as fine lines or striæ traversing its entire thickness. Thus Virchow mentions having seen fat globules penetrating from the intestinal canal through the wall of the cells which cover the lacteals, and Löwe describes in detail the penetration by the spermatozoid of the zona pellucida (wall) of the ovum through one large opening, the micropyle, or through one of the numerous finer canals in the rest of the wall.

The Nucleus and Nucleolus.

The nucleus is the smaller, separated body, of various size and shape, usually somewhat eccentrically situated in the protoplasm which composes the body of the cell. It may be recognised, as a rule, by its comparative opacity, and is made more visible under the microscope by the addition of various chemical reagents, dilute acids, etc.

The essential value of the nucleus, according to Kölliker, who takes a middle ground between the older advocates of the cell with all its parts, and the more modern advocates of the protoplasm theory, is "to secure to the protoplasm a definite form and function, and more especially to officiate as its proper organ of reproduction." The ovum, or primordial cell loses its nucleus, as one of the first signs of development, while the new nucleus, developed later in the egg, is an entirely new formation. As to the spermatozoid, it is wholly and exclusively composed of the nucleus of a cell, the remaining constituents of which have been left behind it in the seminal ducts.

The nucleolus is the still more minute body disposed towards the nucleus and acting for it the same part as the nucleus towards the entire cell. Both of these bodies are to be regarded as masses of protoplasm differentiated from the main mass or developing within the main mass as the youngest or latest additions of matter. When staining matters, carmine, aniline, etc., are brought into contact with the entire cell, the newest matter is deepest stained. The cell wall and the protoplasm just about it are not stained at all.

The Cell Contents or Protoplasm.

If, then, the cell wall be relegated chiefly to a protective office, and the nucleus (with its contents) to the function chiefly of reproduction, it is in the cell contents, the protoplasm, that we must locate the remaining essential processes in the life of the cell. The lowest forms of life consist of protoplasm alone, protoplasm in shapeless mass, without nucleus or wall. Such are the vast masses of gelatinous matter (deep sea ooze) endowed with motion, assimilation, reproduction, etc., which have been dredged (Huxley, Thompson, 1868) from the bottom of the North Atlantic Ocean, at depths varying from 5,000 to 25,000 feet. Much doubt has been cast upon the nature of this so-called Bathybius (*Urschleim*), by the fact that deep ooze has been dredged from other seas not endowed with these phenomena, but the later observations of Bessels (1873) confirm the existence, at the bottom of certain seas, of masses of pure protoplasm, "very sticky, mesh-like structures, with perfect amœboid movements," which "took up particles of carmine and other foreign substances" and which "showed active motion of the nuclei."

The Amœba.

Of the isolated masses of protoplasm, the best known example is the amœba. Towards the close of the last century, O. F. Muller gave the name of Proteus to certain forms of infusoria observed to be in ceaseless motion, and M. Borg de St. Vincent called one of these forms (the proteus diffluens), "*Amiba,*" a name subsequently changed by Ehrenberg, to harmonise it with his etymology, to *Amœba*" (Milne Edwards). Amœbæ are masses of protoplasm which, as a rule, have nuclei but no walls, but since Max Schultze discovered in the Adriatic sea a non-nucleated amœba (the amœba porrecta) this low form of life has been selected from among all the rest as a basis for physiological study.

The physiologist has here, and in similar structures, a case "in which those vital operations which he is elsewhere accustomed to see carried on by an elaborate apparatus, are performed without any special instruments whatever; a little particle of apparently homogeneous jelly changing itself into a greater variety of forms than the fabled Proteus, laying hold of its food without members, swallowing it without a mouth, digesting it without a stomach, appropriating its nutritious material without absorbent vessels or a circulating system, moving from place to place without muscles, feeling (if it has any power to do so) without nerves, propagating itself without genital apparatus. And not only this, but in many instances forming shelly coverings of a symmetry and complexity not surpassed by those of any testaceous animals" (Carpenter).

The best examples of protoplasm devoid of walls or nucleus are the so-called myxomycetes, fungi found in abundance on decomposing vegetable matter, moist flower pots, bark of trees after a rain, etc. The best examples of protoplasm with wall but without nucleus are the hyphens, fungi found on fruits, bread, etc., kept in a warm wet place. The largest specimens are obtained from the surface of manure spread on bricks and kept in moist places. Amœbæ are the best examples of protoplasm with nuclei but without walls. These animalcules are found in myriads in stagnant water exposed to a hot sun. Some forms of amœbæ are, as we have seen, also devoid of nuclei. The mammalian ovum exhibits the typical isolated cell with all its parts, nucleus, contents and wall. It may be readily expressed from the ovary after puncture of the Graafian follicle.

The protoplasm (πρώτος, first, πλασσω, I form), or cell contents, constitutes, thus, the essential element of the cell, while the wall and the nucleus are to be regarded as additions of structure in cells, or masses of protoplasm, differentiated for special purposes or for higher grade of development. The perfect cell, that universally present in the construction of all the organs of animals and plants, so highly developed as to possess organs, consists of contents, wall and nucleus, so that the cell with all its parts must still be regarded as the ultimate physiological element in the body of man.

The Properties of Protoplasm.

In studying the phenomena of life, we have, therefore, to consider the properties of protoplasm as observed in the forms of life consisting only of single and simple masses of protoplasm, and as likewise observed in more complex structures composed of myriads of masses (cells), each individual, independent, and in a sense isolated, yet all connected and brought into harmonious action by common fluids (blood, lymph, etc.), in which they are continuously bathed, and by "facile threads of communication," nerves, bonds and links of association.

We observe, then, first, as the most striking endowment of protoplasm,

The Property of Motion.

Sarcode (σαρξ, flesh) was used by Dujardin (1835) as a synonym of protoplasm, because it implied the property of motion as observed in muscle tissue. This motion may be partial, manifesting itself simply as a protrusion and subsequent retraction of some portion of the substance, or it may, in detached and isolated masses, be general, effecting the locomotion of the entire mass. The amœba, for instance, the individual mass of protoplasm, extends from its substance prolongations to encircle some foreign body, the nutritive principle of which it absorbs and incorporates, to then release itself or flow away from the indigestible residue. A very distinguished botanist was once deceived into the belief that a starch granule had become converted into living protoplasm by observing the disappearance of the granule and its substitution by a moving mass of matter; the apparent substitution being only an envelopment of the granule, for the time being, by a living amœba in its vicinity. The white blood corpuscle may thus gradually protrude itself through interstices in the capillary wall to effect migration to distant parts.

In the early life of all cells (the embryonal stage of complex structures), the property of motion is always manifest, but as the cell matures or becomes senescent, it loses this property in most cases; it becomes quiescent and exhibits its activity only in other ways.

Individual masses of protoplasm being invisible to the naked eye it is only possible to study their motion under the microscope, but the general motion effected by aggregate masses is apparent in the contractility of muscles, locomotion of members, etc. We have in the color changes assumed by various fishes and frogs handsome illustrations of the motion of cells. The change of color is effected by changes of shape in cutaneous pigment cells. The colored masses of protoplasm (pigment cells) approach to or withdraw themselves from the surface and thus vary the color of the animal. If the pigment cells move uniformly in the skin, the animal is uniformly varied in color. If only some of the cells move, the animal appears spotted or striped or ringed, etc.

The Color Changes of the Chameleon.

The chameleon is so universally known for its changeability as to have had its name used ever since Tertullian as an epithet to express sycophancy and vacillation of purpose. Prior says:—

> "As the chameleon which is known
> To have no colours of his own
> But borrows from his neighbor's hue
> His white or black, his green or blue."

And Dryden perpetuates this and a greater fallacy in the lines:—

> "The thin chameleon *fed with air* receives
> The colour of the thing to which he cleaves."

But the chameleon is not so changeable as has been represented. It is not able to assume any color whatever, nor is it able to take on the color of every object upon which it may rest. Basking in the sun it may appear blue, green or red, according to the incidence of the light, or it may appear dark, black or iridescent. As different chameleons differ in the natural color of the unpigmented part of the skin, an individual may be white or yellow. Moreover it may show gray and brown. All these colors it may exhibit, but it may not exhibit all colors. The change of color in the chameleon is due to the presence in the skin of pigment cells having prolongations which, under nervous influence, may penetrate the interstices of the superjacent layer of unpigmented skin tissue, and spread out to cover the surface wholly or in part. The physical laws regulating the reflection, absorption and interference of rays of light in different media fully explain the different colors the animal may assume. What especially interests us in this connection is the property of motion with which the pigment cells are endowed, and which enables them, in obedience to stimulus from the nervous system, to assume different shapes and positions with reference to the super and circumjacent skin tissue and subjacent blood-vessels. When a chameleon is poisoned with strychnia it becomes uniformly light in color from a complete retraction (tetanus) of the pigment cells. This retraction represents the active condition of the cells. When the animal is sick, it is spotted, some of the cells being retracted, others protruded. Section of individual nerves of the skin produces the same effect, corresponding cells being passively protruded (paralysed). The black spots now show dendritic prolongations. Section of a series of nerves produces a black stripe. A mechanical, chemical (turpentine) or electric irritant applied to the skin induces a retraction of the cells, and thus gives rise to a light or yellow color at the surface of irritation. The cells relax and spread themselves out (passively) under the light and heat of the sun, hence, the animal under such conditions is dark or black. In darkness the cells are actively retracted, hence, the animal is pale. If parts of the body be protected from the sun, as by bands of varnish, these parts remain light, while the rest of the body is dark. Psychical influences likewise affect its color.

In the passive state it is uniform in hue; excited after food, in strife, etc., it is variously tinted. Thus "so far from being a symbol of falsehood, the chameleon is rather a symbol of frankness, as every emotion is depicted upon its surface" (Brücke).

But the motion of pigment cells is not independent. It is directly under the control of the nervous system. The motion of muscular tissue, though inherent in the muscle protoplasm itself is evoked by the nervous system. Of course, in speaking of independent motion, it is not for a moment intended to imply a spontaneous motion. It is simply meant that we are ignorant as yet of the external influences which induce the motion. As Stricker has observed, we no longer term the movements of striated muscle spontaneous, because we know the external influences or stimuli through which it can be excited. "And so, also, there can be no doubt that as soon as we have acquired a knowledge of all the external influences by which movements in protoplasm can be induced, we shall cease to term them spontaneous. Thus, in stating that protoplasm is capable of active or vital (spontaneous) movements, we have by no means admitted the existence of an immaterial force" (Stricker). The best example of protoplasmic motion entirely independent of the nerves, is that exhibited in the undulations of the ciliary processes upon the surface of certain epithelial cells.

Ciliary Motion.

Ciliated epithelial cells are cylindrical, conoidal or goblet shaped masses of protoplasm, from whose upper free surface protrudes a thicket (not simply a few, as always represented) of fine, hair like, processes, the cilia. Such structures have long been recognised in certain infusoria, for which they furnish means for locomotion, prehension of food, and for which, also, by creating currents, they minister directly to respiration. Purkinje and Valentin discovered their existence in vertebrate animals and in man. Such cells line the entire respiratory tract from the nasal cavities, except the space within the anterior nares, down to the finest bronchioles (but not the air cells). Ciliated cells tapestry also the cavities accessory to the nasal, the antrum of Highmore, the frontal sinus, etc., the Eustachian tube, and for the most part, the cavity of the drum of the ear. A tract of epithelial cells is also found in the epidydimus, the efferent ducts of the testicles, and in the female, in the parovarium, the Fallopian tubes, and the body of the uterus, extending into the uticular glands. Ciliated cells, though much smaller and more delicate, occur also in the various cavities of the nervous system; in the lateral ventricles, the floor of the fourth ventricle, and the central canal of the spinal cord.

The cilia (cilium, an eyelash), are for the most part sabre shaped, with a broad attached base and a free pointed extremity. They are implanted directly into the protoplasm (the cell), of which they are part, and not inserted into a membrane or an upper distinct layer of protoplasm as once believed. At rest they are slightly inclined, mostly towards the exterior of the tube or cavity in which they are found. In motion they strike with their broad or flat surface and return, like oars in skillful hands, by feathering the edge, to nearly, but not quite, a perpendicular position. The stroke is the result of an active contraction (motion) of the protoplasm while the less quick return is due to a simple passive elasticity. But the cilium in its stroke is not passively moved by the contracting protoplasm. On the contrary, it is the cilium itself which is endowed with the contractility, and the cell when free (as in the detached masses found in the secretion of coryza), is passively moved about by its vibratile cilia. This contraction and relaxation is exceedingly rapid, too rapid, indeed, to be individually visible. Cilia move in the frog at the rate of twelve times in the second, and in warm blooded animals much faster. It is only when contractility has become partially exhausted that individual motion may be observed. In molluscs, where the cilia are of very great size, their motion produces undulations which may be seen in its totality as glittering waves even by the naked eye. The motion of tracts of cilia has been not inaptly compared to the undulations of a field of grain agitated by the wind, or to the glistening of a river in the sun.

Conditions Influencing Ciliary Motion.

Cilia are entirely independent of the nervous system. Section or stimulation of nerves produces upon them no effect. They contract when removed from the body, and survive somatic death for hours, even nine hours in the frog. Nevertheless ciliary motion in life is not irregular; all the cilia in a given tract move in a definite direction, and produce definite currents in the circumambient fluids. It is for this reason that particles of mucus or other foreign bodies are propelled upon the surface, tossed from place to place, towards the exterior. The force of cilia is really astonishing. Particles of coal dust suspended over them by means of a drawn thread of sealing wax are lifted and pushed on at the rate of $\frac{1}{200}$ of an inch per second. It was by means of such an experiment that Kistiackowsky was able to prove that induced currents of electricity stimulated the cilia, contrary to opinions expressed hitherto, to greater activity, or renewed it after a period of quiescence. Heat quickens, cold retards their motion. The activity of the movements of protoplasm in general is greatest at about 100° F. (38° C.). At 32° F. (0° C.), they become extremely sluggish, or ceases altogether. The ova of trout, however, undergo segmentation perfectly in iced water, whilst they soon cease to move at ordinary temperatures. Dilute alkalies act as direct stimulants to ciliary motion, partly by simply diluting the thickening mucus in which they float and partly by increasing oxidation. Chloroform suspends their activity, or in excess disorganises and destroys the cells.

Ciliated epithelial cells are best obtained for study by scraping the roof of the mouth or the pharynx of the frog. A few cells may be detached in man by inserting a feather into the upper cavities of the nose. The largest cilia are found in the molluscs, in the so-called beard of the oyster or clam. Tracts of cells are secured by dissecting off parts of the pharyngeal mucous membrane of the frog. Calliburces constructed a very elegant apparatus to cause cilia in motion to strike upon and revolve a glass cylinder and thus record their own velocity of movement. Bowditch exhibited this motion more simply and effectually by cutting through the body of a frog just below its anterior extremities, after destruction of the spinal cord, and passing a glass rod through the œsophagus. The body of the frog is gradually pushed along the rod by the motion of the œsophageal cilia. The front part of the jaws should be cut away to prevent too great friction, and the rod should be dipped in salt water to secure the best action of the cilia. If the œsophagus alone be slipped over the tube the motion will be much more apparent.

Motion of Other Cells.

A spermatozoid is a detached ciliated cell; the whip-lash tail is the cilum and the head is the nucleus of the cell. The spermatozoid, all moving protoplasm, indeed, is affected in like manner with ciliated epithelium by the various agents mentioned.

Motion has been studied also in the lymph and pus corpuscles, in cartilage and in connective tissue cells. Certain corneal corpuscles have been observed by Recklinghausen to penetrate tissue interstices and wander about, like the white blood corpuscles, to considerable distances. It is by means of motion of this kind that young cells may arrange themselves in position in the original construction of the various tissues and organs

But the motion of the highest physiological interest in this connection is that which takes place in the interior of the cell itself. Such movements are known as

Molecular Movements,

because they consist of agitations, tremblings or rotations of the fine granules in the protoplasmic mass. These movements are not to be confounded with those exhibited by inorganic bodies floating free in fine particles, the movement described by Brown, and known as the Brunonian movements, for in the case of the inorganic body the movements are oscillatory or merely passive followings of the currents in the fluids. Protoplasmic molecular movement is active and translative from place to place. It may be seen to advantage in the cells of the salivary glands, in living blood corpuscles (white) or in pus corpuscles when water is added to the fluid in which they float. These movements cease only with the death of the cell. A stroke of electricity which kills the cell stops the granular movement at once, proof that it is in no sense a passive phenomenon. The hair of the stinging nettle exhibits protoplasmic molecular movement even more clearly than any animal structure. Such a hair consists of one elongated cell filled with intra-cellular fluid; its transparent wall being lined with soft protoplasm.

The molecules or granules in the protoplasm not only tremble like the salivary corpuscles, but they actually circulate in a regular stream. The protoplasm itself undulates in different directions. A shock from a magnetic electromotor apparatus arrests the regular system of waves, and suddenly projects the protoplasm in promontories into the intra-cellular space. During this attack, so to speak, the molecular motion ceases, to recur only when the protoplasm resumes its normal motion.

Molecular Changes in the Ovum.

The ovum, or primordial cell, is, however, here again, the best object for study of this kind of motion. The ovum in both plants and animals is the continual seat of molecular motions of the most active as well as curious character. In its development the nucleus of the ovum first becomes elongated, spindle-shaped and covered with fine threads or hairs. The granules of the protoplasm now move about to arrange themselves in regular lines irradiating from the ends of the nucleus and finally the whole protoplasm splits in two, forming two cells, a smaller, so-called cemetery-cell, containing the products of excretion, which entirely disappears, and a larger formative cell which contains all the elements essential to the formation of the new being. In ova without special walls, enveloped only in the mucus from the maternal genital canals, a single spermatozoid, out of the 70–80 upon the surface of the enveloping mucus, penetrates the mucus to reach the yolk. "At the moment when this penetration is effected, the yolk, which had hitherto presented a uniform arched surface, suddenly projects an elevation towards the head of the spermatozoid, seizes it, surrounds it and draws it with a celerity which almost escapes vision, into the interior of the egg." The tail of the spermatozoid now disappears by solution in the yolk protoplasm, and the head gradually travels towards the nucleus of the ovum. So soon as contact is effected the two bodies roll about each other several times and then fuse together to become the new nucleus of the ovum. Hereupon ensues the division and subdivision of the new nucleus, until the whole ovum has undergone the process of segmentation into daughter cells, which arrange themselves into three layers, the blastodermic layers, containing the elements of construction of the whole body. In ova provided with a distinct wall (zona pellucida) there may be usually detected somewhere in the wall a large opening, the micropyle, for the entrance of the spermatozoid. The cell wall is often penetrated, besides, by very fine radiating canals, in every one of which is a thorn-like protrusion of the yolk stopping up the canals, like bottle stoppers, to prevent the entrance of fluids in which all ova float. A cord or track of clear protoplasm, the so-called seminal cord, passes from the micropyle to the nucleus of the ovum, as a road along which the spermatozoid may pass to the nucleus of the ovum.

Now the most serious accident that can befall an ovum is the accidental penetration of more than one spermatozoid. Malformations and double monstrosities always occur after such accidents. But the ovum is protected against these accidents by a provision which is as curious as effective, and, as a striking exemplification of molecular motion, is worthy of mention here. In the naked (wall-less) cells, at the moment when the hillock of yolk has seized upon the first penetrated spermatozoid, "a fine, delicate, but very resistent membrane immediately—so quickly as to be invisible to the eye, in its stages of formation, a kind, therefore, of chemical deposit—covers over the whole surface of the yolk," to effectually bar the passage of further spermatozoids. In ova with walls, a number of spermatozoids are seen gliding, head first, about the surface of the wall.

Finally, one succeeds in reaching the micropyle. "So soon as this happens, the seminal cord is at once torn away from the micropyle and the thorn-like protrusions of the yolk are at once withdrawn from the radiating canals in the zona pellucida, whereupon water streams into the radiating canals and through the open micropyle, to spread out between the surface of the yolk and the zona pellucida. The zona pellucida (cell wall) is thus lifted away from the yolk (cell contents) and thrown into irregular folds to oppose an insurmountable obstacle to the penetration of even a second spermatozoid" (Löwe).

The motion of the molecules in the ovum is the cause of its development. That is, motion is the

Essence of Reproduction.

The assistance of the male element is not by any means a necessity in reproduction. In many animals, notably in insects, continued progeny (ten to twelve generations) is produced without copulation. Generation of this kind, partheno-genesis, or virgin generation, instead of being a mysterious exception, is the rule in all animals up to a certain grade of development. Bischoff found that all the first stages of development, disappearance of the germinal vesicle, appearance of the new nucleus in the interior of the yolk, condensation and volume reduction of the yolk, movement phenomena in the yolk, finally even the first stages of segmentation, all these changes occur in eggs which have never been impregnated, and in eggs which are never impregnated at all, but which have been discharged from the ovary simply on account of their maturation. Moquin Tandon has seen the process of segmentation of the yolk in unimpregnated frog's eggs, and Van Beneden has shown that the first phases of development in the rabbit are entirely independent of impregnation. These changes are not dependent, therefore, upon the formal union and copulation of a sperm and germ cell, nor upon any chemical or dynamical effect of the spermatozoids, for they occur without the presence of spermatozoids at all. They depend upon the motion inherent in the molecules of the ovum itself. But, in the rule, we observe that the intensity of this motion is not sufficiently great to lead to further development and production of form. It must receive additional force, and probably also a definite direction, in order that the further movements of development, those requisite to the complete construction of the embryo, may ensue. The egg receives this further addition, strength and direction of motion from the spermatozoids, whose individual mass movement is proof that the matter of their composition is also in the condition of intense activity. Bischoff in making this statement concludes: "we possess nowhere else such a perfect insight into the cause of organic movements as here, and the view which this insight gives will be as satisfactory to the reasoning mind as every other application of the law of the conservation of force."

The case of the bee affords a striking confirmation of the fact that development up to a certain grade is possible without copulation, while more perfect development requires assistance. Thus the queen bee in captivity or isolation continues to breed drones (males) almost indefinitely, and under conditions which preclude the idea of any utilisation of sperm stored up in the past, while the production of workers (females) only ensues after copulation. In fact, the observations of Leuckart and Siebold prove that spermatozoids are always found about the micropyle of the ova of females, and never about the ova of males. But among the sack bearing insects (psychides) the sex is reversed, that is, the production of males requires copulation (Wundt).

The essence of reproduction, therefore, so far as may be comprehended by the limited understanding of man, is a transmission of motion, as the remaining manifestations of protoplasm (the various phenomena of life), are transmutations of some physical force.

LECTURE VII.

PROTOPLASM AND ITS PROPERTIES.

CONTENTS.

The Chemistry of Organic Matter—The Ultimate Elements—The Proximate Principles—Albumen and its Products—The Chemistry of the Cell—Absorption and Assimilation—Metabolism—Oxidation Processes—Oxidation in the Ovum—Oxidation in Muscle—Oxidation in the Blood—Oxidation in Nerve Tissue—The Quantity of Oxygen in the Body—The Genesis of Protoplasm—Spontaneous Generation—Omne Vivum ex Ovo—Reproduction and Nutrition—Modes of Cell Genesis—Death of Cells—Recapitulation—Classifications of the Tissues.

We have already regarded the matter of the body, the protoplasm, from an anatomical stand-point and before continuing the study of its properties we shall have to survey it from a chemical point of view.

What seems especially striking in the

Chemical Analysis of Organic Matter

is the simplicity of its elementary construction. The number of elements entering into its composition we discover to be extremely small. Of the sixty-four ultimate elements into which the matter of our earth may be resolved but four take any prominent part in the manufacture, so to speak, of purely organic matter. These are carbon, which is absent in no organic body, and oxygen, hydrogen and nitrogen. But in the construction of the more complex animal and vegetable bodies we encounter also seven other elements, viz., sulphur, phosphorus and iron, as elements most widely diffused, and chlorine, potassium, sodium and calcium as elements most rarely met. The first four mentioned elements, carbon, oxygen, hydrogen and nitrogen, are the essential elements; the rest are said to be incidental elements. I have here before me a glass of water. I drop into it a small piece of coal. We have now in this glass hydrogen and oxygen in the water, nitrogen (with oxygen) in the air and carbon in the coal, all the essential elements, and in some cases the only elements, entering into the composition of organic matter.

The Proximate Principles.

But no familiarity with the characters or properties of these ultimate elements may acquaint us with the properties of their compounds, the results of their combinations, the so-called proximate principles, as they are encountered in the body. No knowledge, for instance, of the peculiarities and characteristics of chlorine, a heavy, greenish-colored gas, with bleaching properties, or of sodium, a whitish mineral which burns upon the surface of water, would inform us as to the properties and characteristics of the chloride of sodium (common salt), a substance as different from either of the elements of which it is composed as they are from each other. In the study of the structure of the body from a chemical point of view, it is the combinations of the elements, and not the elements themselves, with which we have to deal; the proximate principles, and not the ultimate elements, present the peculiarities pertaining to living things.

There are organic compounds which consist of but two of these ultimate elements, but the great majority of them are made up of three, viz: carbon, hydrogen and oxygen. These carbo-hydrates owe their name to the fact that they are composed of, besides carbon, hydrogen and oxygen, in the proportion to form water. Starch and the various sugars, so easily mutually convertible by the addition or abstraction of water, are examples of the carbo-hydrates. The closely allied fats have an excess of hydrogen, so that all these substances are often grouped under the head of the hydro-carbonaceous compounds.

Another group of organic matters contains, in addition to the three elements mentioned, nitrogen. They are, therefore, known as the nitrogenous in distinction to the non-nitrogenous principles. To this group belong the complex products, the albumenoids (including hæmoglobin and vitellin), which also contain sulphur, phosphorus or iron. The white of egg is a typical albumenoid substance.

Chemical analysis of the body discloses, besides these two classes of principles, the nitrogenous and non-nitrogenous, a third group of inorganic or mineral principles, as water, common salt, phosphate of lime, etc., contributing to the formation of tissues and juices of every character and consistence.

Albumen and its Products.

The chief constituent of protoplasm is albumen in some one or other of its numerous forms. Albumen with water in considerable amount, mineral matters and fat, these are the substances which compose the animal cell. Protoplasm is thus a peculiar albuminous compound, tough and viscid before undergoing subsequent change, which coagulates under heat (or at the death of the cell, as in rigor mortis), and which is swollen up or gelatinised, but is not dissolved, by the action of water.

It is a humiliating confession to have to make, but it is true, as Frey remarks: "This is about all we know, at present, of this important compound, protoplasm."

We recognize in albumen, in some of its forms, the fundamental substance in the composition of protoplasm. In the lowest forms of life, at all times, and in the higher forms in the embryonic stage, albumenoid (protein) bodies are universally present. But as development advances in the more complex forms the differentiation of individual masses of protoplasm into separate tissues and organs is characterized by a change of the protein bodies into some of their more permanent derivatives, as chondrin, elasticin, etc. What especially characterizes the albumenoid bodies is their instability of structure, that is, the readiness with which they may be broken up into new compounds. In this decomposition, the force latent in the albumen is translated into active forms with the development of various decomposition products which escape in the secretions. Such products are urea, leucin, tyrosin, creatin, creatinin, glycogen, peptones, and ferments. Some of these products, glycogen, peptones, etc., are true secretions, having further purpose to subserve in the body; others, urea, creatin, creatinin, are veritable excretions, effete matters of no further use. Very grossly considered, the first mentioned useful products correspond to the steam of the engine; they are the agents of force; while the second class of useless products are the ashes and smoke; they must escape from the body, as their accumulation in it extinguishes the processes of life.

The Chemistry of the Cell.

The protoplasm (or cell contents) is thus composed of albumen in some of its forms, of water, of mineral matter and of fat. The outside or cortical layer of protoplasm (the cell), when such a layer is present, differs from the inner substance in its greater density. The albumen is here converted (differentiated) into elasticin, which, as its name implies, is more resistant and elastic, and hence is better qualified to serve as a protection to, and to regulate diffusion for, the more delicate protoplasm inclosed.

The nucleus of the cell, again, may also be differentiated into a wall and more fluid contents chemically somewhat different, in turn, from the wall and contents of the main cell. Thus minute granules are readily precipitated in the nuclear contents by the addition of alcohol and acids, while the wall of the cell differs from that of the nucleus by the greater solubility of the former in alkalies. The nucleolus, from its high refracting properties, is supposed to consist largely of fat.

With this glance at the chemical constitution of the cell we are better prepared to continue the study of its properties.

Absorption and Assimilation.

Cells have the power to absorb, assimilate or store up material from without, to elaborate or transform the material thus absorbed, and to filter out, excrete or eject material from within.

In the ordinary growth and nutrition of the cell new matter passes by penetration, imbibition or osmosis, directly into the substance of the cell. The whole collection of cells constituting the body may be roughly compared to a sponge soaked in nutrient fluids. These fluids penetrate the wall, and thus constantly contribute to the cell new material. Just as every plant absorbs from the earth the particular salts essential to its growth, does each cell drink up from its earth, the blood and the part of the body in which it is found, the particular elements essential to its growth and work. The cell in this way feeds itself, absorbing with what seems a selective agency (chemical affinity) the material upon which it can live and work, and with some discrimination refusing to absorb useless and innutritious matter. The new matter may then be transformed into the protoplasm of the cell (assimilated), or it may be stored up for other use in its work. Thus the protoplasm grows, imperceptibly increases in size, or fills itself with foreign bodies (blood corpuscles, fat cells, coloring matters), which may be seen entire or in fragments in the body of the cell.

The Metabolism of the Cell.

The transformation of matter (metabolism) in the interior of the cell, is the highest physiological endowment of protoplasm. In this process, chemical changes, to large degree inscrutable as yet, are incessantly at work. Muscle-cells and nerve-cells elaborate in this way their irritability and other properties which endow them with their peculiar physiological dignity as the master-tissues of the body. Gland-cells manufacture ferments; as the gastric epithelium, pepsin, the pancreas, pancreatin, or new compounds, as the mammary cells, milk sugar, liver cells, glycogen; from the disintegration and rearrangement of matters pre-existent in the blood. Lastly, certain masses of protoplasm (cells) come to be set apart for the purpose simply of filtering out from the blood and eliminating from the body various products of decomposition and waste.

The most important factor in effecting these various metamorphoses is oxygen gas. To great extent the chemical changes in the cell, the metabolism of the cell, as it is called, are

Processes of Oxidation.

The various excretions of the animal body are, as we have seen, for the most part, products of oxidation. Of these excretions, some, carbonic acid gas and water, are completely oxidised products, while others, the urates, for instance (but not urea) escape only partly consumed (oxidised) and must undergo further oxidation outside of the body before they are resolved into the fully oxidised products, water, carbonic acid gas, ammonia, etc. These finally oxidised products thus restore to the earth and air what was abstracted by the plant.

> "See dying vegetables life sustain,
> See life dissolving vegetate again,
> All forms that perish other forms supply,
> By turns we catch the vital breath and die." Pope.

Oxidation (union with oxygen), so far as we can follow it, causes the decomposition or splitting up of compound into simple bodies. Deoxidation (abstraction of oxygen) causes or attends the rearrangement of simple into compound bodies. The plant (vegetable) cell has the power, under the light and heat of the sun, to disengage oxygen and rearrange the atoms of simpler into more compound bodies. In this way the plant-cell builds up and stores up these compounds as latent force. The animal cell (protoplasm) has the power to reduce these compounds, with the aid of oxygen, and set the latent force free.

Oxygen being thus the principal agent in decomposing the matter of the animal cell, and setting free the force which it contains, we may now consider its appropriation by the various organs somewhat in detail.

Oxidation in the Ovum.

To commence, then, at the beginning of the cell, it is observed that the ovum breathes. The butt end of the chicken's egg has a cavity filled with air, which, according to Bischoff, contains, on the average, 23. 5 per cent. (more, thus, than the atmosphere, which contains but 20 per cent.) of oxygen gas. This cavity is a reservoir of air for extra demands. Oxygen continually penetrates the shell of the egg in greater quantity as the shell grows thinner, in correspondence, thus, with the increasing demands of increasing development within.

In Baumgärtner's artificial hatching experiments, so conducted that the absorption of oxygen and exhalation of carbonic acid gas could be accurately measured, it was observed that the egg gained in twenty days (up to the time of the escape of the young chicken from its cavity) 26.82 per cent. in weight; a gain attended with the absorption of 6.29 per cent. of oxygen, and the escape of 8.412 per cent. of carbonic acid gas, and 24.69 per cent. of water. The volume of the oxygen absorbed from the air is always greater than that escaping with the carbonic acid gas, as the oxygen not only contributes to the formation of carbonic acid gas and water, but is also used in the formation of other products remaining in the substance of the egg.

Though there are many recondite chemical processes continually in operation in the body, most of the changes connected with the development of force are simple oxidations. The force-material of the body may be said, therefore, to be represented by oxidisable (organic) combinations on the one hand, and by free oxygen on the other.

The direct absorption of oxygen gas has been observed by Kühne, in the case of the ciliated epithelial cells. The movements of cilia are intimately connected with the consumption of oxygen. They cease in its absence, and they cannot be started again without it.

Oxidation in Muscle.

The contraction of muscle protoplasm is as closely connected with the absorption of oxygen, and the excretion of carbonic acid gas. But it is not so much the muscle substance itself that is oxidised in the production of muscular force, as the non-nitrogenous elements of the blood, circulating through the muscle. For, it has been now pretty clearly established that the urea, urates, etc., products of the waste of muscle itself, are not increased in the excretions (urine) in correspondence to muscular exercise. On the contrary, the increase concerns the carbonic acid gas exhaled from the lungs, proof that it is the carbo-hydrates of the food, and not the nitrogenous muscle itself which serve as fuel for the muscle machinery. When a muscle is at rest, the blood in its emulgent veins is red in color, but after contraction its escaping blood is deoxidised to a blue color, showing that oxygen is used up in the blood. But oxidation of muscle-substance itself does take place, in some, though slight, degree. For, aside from the presence or absence of its products in the urine, a muscle will continue to give off carbonic acid gas for a time, even when washed free of blood, or even when placed in an atmosphere absolutely free from oxygen, as in hydrogen gas. The production of carbonic acid gas in this instance depends, of course, upon the presence of oxygen, stowed away in the muscle previous to the experiment. The protoplasm of the tissues is everywhere the chief seat of the processes of oxidation. If a separate muscle, free of blood, be inclosed in a gas chamber, it will absorb more oxygen, and give off more carbonic acid gas during contraction than during rest. Examination of the blood of the femoral veins in the frog, after galvanisation of the posterior extremities, shows an increase in the amount of carbonic acid gas.

Oxidation in the Blood.

But the blood is also a vast field for the operations of oxidation. The hæmato-globulin, the albumenoid principle of the blood corpuscles, collects it at the lungs, and carries it in loose combinations for surrender to the various tissues of the body. Then the blood corpuscles are endowed with what we might term a magical power of converting oxygen into ozone. Ozone (nascent oxygen) is a peculiar modification of oxygen, with much higher oxidising powers than simple oxygen. The molecule of oxygen being represented by one O, that of ozone is triplicated. Ozone is O_3, so that it has much wider range of affinity. If a drop of blood be let fall upon a piece of ozone test paper (made test paper by having been saturated in tincture of guiacum, and afterward dried) a deep blue color forms about it. This is the reaction of ozone. The serum of the blood will not show it at all (Schmidt). The ozone of the blood can not be directly established in this way, as it is at once used up for oxidation purposes. The ozone thus proven present has been just created by the blood corpuscles.

The blood, again, very greatly assists the oxidation process by its alkalinity. All alkalies have this property. Many organic compounds, not at all affected by oxygen, are at once attacked in the presence of a free alkali. The organic acids ingested into the body pass over unchanged into the urine, or, at most, are oxidised to very slight degree; but when they reach the blood in alkaline combinations, they are at once completely oxidised, and appear as carbonates in the urine. Gallic and pyrogallic acids, are not oxidised in the atmosphere, but on the addition of a free alkali, oxidation occurs so quickly that the solution of pyrogallic acid can be used in eudiometry, and sugar becomes so oxidisable in the presence of a free alkali that it will abstract a part of its oxygen from a metallic oxide, and thus reduce an oxide of copper, for instance, to a sub-oxide (Trommer's test for sugar). According to Gorup-Besanez, even ozone will not oxidise the organic acids except in the presence of a free alkali or alkaline salts (Vierordt).

Oxidation in Nerve Tissue.

Nerve-force was thought, at least, to be generated more directly by oxidation of nerve-substance, as the quantity of alkaline phosphates in the urine, the product of oxidation of the phosphorised fats of nervous tissue, stands in close correspondence to the amount of brain-work. "We may rightly liken the brain," said Carpenter, "to a galvanic battery, and the blood to its exciting liquid. When the circuit is closed, a rapid oxygenation of the nerve-substance, as of the zinc of the battery, takes place; and a corresponding equivalent of nerve-force (which seems closely related to, but is not identical with, electricity) is generated." But the fact alone of the enormous supply of blood to the brain; one-fifth of the whole amount; though the brain weighs only one-fortieth of the entire weight.of the body; would indicate that nerve-force, as well as muscular, is almost entirely derived from oxidation of material furnished by the food.

Paul Bert has been able to prove that the loss of consciousness and motion, which occurs immediately when the blood-current to the brain is interrupted, is due to the lack of oxygen rather than of any other nutrient matter. In cases of partial asphyxia, induced by abstraction or rarefaction of oxygen (as in mountain ascents) the faintness and exhaustion are immediately and completely relieved by the inspiration of oxygen gas or of air which is highly charged with it. The transformations of force that occur in the body, that is, the manifestations of life, are, thus, pre-eminently, processes of oxidation.

The Quantity of Oxygen in the Body.

In recognizing this fact we would be led to believe that the quantity of this gas, and its most frequent product, carbonic acid, in the blood and tissues would always be very great. We observe, however, the very reverse to be true. There can, at no one time, be collected from the blood more than four grammes of oxygen or carbonic acid, and adding to this the quantity present in the tissues (a quantity which can not yet be definitely ascertained, but which is known to be very small), the whole amount of these gases is still comparatively little. But this small amount present at any one time is no true criterion of the sum-total absorbed in the course of time. For this small quantity is being so continuously received (and consumed) as to amount in the course of a year to several hundred pounds. In fact, more oxygen is ingested than food (aside from drink). The absolute indispensability of oxygen gas from moment to moment, is proven by the serious changes that at once ensue in the body when its quantity is diminished in the air. Other nutrient matter may be absent from the body for hours or for days, without discomfort, but the absence of oxygen for a few seconds or minutes produces serious suffering. It is the long subjection of individuals with inherited vulnerable constitutions to an atmosphere whose oxygen has been reduced (as in factories, badly ventilated houses, etc.) that forms the principal factor in developing phthisis, pre-eminently a disease of modern civilisation. And fresh air in abundance is the only specific in its cure. Fortunately, oxygen exists in nature in sufficient abundance, for all the wants of protoplasm. It forms eight-ninths of the water of the globe, nearly one-half of the solid crust of the earth, and one-fifth of its air.

Oxygen is, in short, an essential constituent of living protoplasm, which develops only at the bottom of an ocean of it, thousands of cubic miles in extent. The atmospheric ocean, which is as much a part of the earth as its water or its salts, is an inexhaustible, a perpetually-filling reservoir of oxygen gas.

We have now to consider the mode of origin or birth of protoplasm, and its mode of dissolution or death.

The Genesis of Protoplasm.

When the microscope first began to disclose its revelations concerning the construction of living things, it was hoped that we were at last in possession of the means that would lift the veil of mystery concealing the genesis of life. If was believed that it would be only necessary to perfect the instrument for the highest magnification to enable us to see the first aggregation of atoms to constitute life. It is needless to say that such extravagant conceptions soon proved to be delusive. With the microscope on the one hand, and chemical analysis on the other, the physical basis of life was soon resolved into its histological and chemical elements; but no peculiar principle of life was ever thus discovered. It seemed, indeed, a justification of the exclamation of Schiller:—

> "Und noch Niemand hat erkundet
> Wie die grosse Mutter schafft
> Unergründlich ist das wirken
> Unerforschlich ist die Kraft."
>
> (As yet no one has discovered
> Nature's secret to produce;
> Still impenetrable her method
> Yet inscrutable her force).

The microscopists soon found themselves, said Leydig, in the predicament of individuals who had long studied from afar the appearance of a meadow or a forest. They thought that a nearer approach would inform them about the germination, the growth and the coloration of the plants. Many new observations they did make, it is true, but the puzzling riddles remained the same. They stood before the same questions, with the difference only that they could now study the changes in each individual plant, which they could observe before upon the whole green surface.

The physiologist thus, aided with the microscope and the test-tube, took only a closer view of the individual elements aggregated in the construction of living things.

In the impossibility, then, of recognising in the construction of animate bodies any elements or principles different from the inanimate, the question at last arose: Is there really any such difference? Thus the question stands at the present time, the burden of proof resting upon those who still maintain the existence of such a difference.

The question of spontaneous generation (autogeny) is now being examined and discussed with even more interest and with more probability of final solution than ever before in the history of science. The doctrine of evolution; which may now be regarded as an accepted fact, and which must soon become incorporated into the curriculum of our common schools; followed to its utmost limits, compels the ultimate admission of the spontaneous genesis of living matter. But an inference, however legitimate or rational, does not constitute a fact in natural or any other branch of science. If the question could be settled by the mere expression of opinion, I should say, with becoming diffidence, that for my own part, I side completely with Prof. Owen, the highest living authority in comparative anatomy, and until very lately, with Quatrefages, the most dangerous opponent to the theory of evolution, when he declares himself the champion of spontaneous generation and maintains, as in the last pages of the third volume of his Anatomy of the Vertebrates, that the formation of living beings out of inanimate matter by the conversion of physical and chemical into vital modes of force is a matter of daily and hourly occurrence. But you will accept as conclusive no opinions. I leave you, what you will doubtless exercise anyhow, the widest latitude of belief, until proof positive shall have been advanced. But I warn you that there is here, as every where in science, no room for fancy, feeling, or prejudice. Cold as ice, clear as crystal, science is a synonim of truth. We cannot mould the truth to our wants and fancies. There is nothing left but to adapt ourselves to truth, whatever wreck of prejudice its revelations may imply. Above all things, truth.

Whatever may have been the genesis of protoplasm under the very different conditions of the primeval world, or whatever it may be now under conditions somewhat similar, at the bottom of the sea, for instance, are questions still unsettled. So far as we have positive knowledge, and it is of facts alone that we have any right to speak, every cell arises from a pre-existent cell.

Omne Vivum ex Ovo

and *omnis cellula e cellulis* are other well-known axioms, expressive of the exclusive derivation of new protoplasm from older protoplasm before it. Science at present recognises no other birth of protoplasm save that derived from parentage. The microscope, in discovering the eggs of plants and animals in concealed places, has put to flight many wild ideas concerning the spontaneous generation of animal and vegetable life. And when these ova or germs have been so minute (in the case of bacteria, etc.) as to have evaded the highest powers of the microscope, a beam of electric light (Tyndall) has disclosed to the naked eye myriads of combustible (organic) particles, the cultivation of which in breeding experiments (Dallinger & Drysdale) has resulted in visible forms.

Reproduction and Nutrition.

In our day we regard the reproduction of protoplasm entirely as a phenomenon of nutrition. It is part of the chemical nature of protoplasm that an isolated mass of it, increased by assimilation to a certain size, has the disposition to divide, the divisions again dividing, and so on, in the formation of new masses, isolated as before. Reproduction is division and separation in growth beyond the natural limit of size. Nutrition and reproduction are, as we have seen, the fundamental characteristics of protoplasm, and they stand in the most intimate relation toward each other. One continues the individual, the other continues the species. Nutrition consists of a constant change of matter in the body of the individual; reproduction of a constant change of individuals. Nutrition, in its essence, is only a reproduction of atoms of matter in the body of the individual, which atoms, when increased beyond the natural limits of size, separate to reproduce new individuals. Hence it becomes a physiological law that a more rapid nutrition implies a more rapid reproduction. The better fed domesticated animals breed faster than their ancestral wild forms. More human beings are born in times of plenty than in times of famine. Of course, if the nutritive matter be consumed in the production of other forces, as in the growth of the body, muscular or mental work, the power of reproduction is limited. During youth and adolescence the force of reproduction is absent entirely, or is very limited. Animals made to perform mechanical (muscular) work have less progeny (stallions, etc., are kept idle in the stalls); and human beings of high mental activity are comparatively infecund. Nothing so completely detracts from muscular and mental force as venereal excess.

Modes of Cell Genesis.

With this knowledge of the physics of reproduction, we are not surprised to learn that its material manifestations are simply divisions of the parent cell. This division may concern the protoplasm first, so that a more or less central constriction, vertical or horizontal, deepens to a furrow, and finally completely separates the main mass and its nucleus (when it exists) into two, each of which then commences its independent existence. In more complex structures the division of the generative cell (ovum) proceeds, each division subdividing, until finally the original cell presents the appearance of a mulberry. This process of segmentation, as it is called, provides separate atoms in each part of the subdivided cell for the construction of separate organs and tissues. The wall of the original "mother" cell may remain intact while this "endogenous" production of new cells is taking place within it, and may even take part in the construction of the new product, or it may burst, as it were, and permit the new "daughter" cells to escape and provide for themselves. The ovum or primordial cell is a typical example of the first method of procedure, cartilage cells of the second. In the cartilage cell, as in the white blood corpuscles of mammals, birds and amphibious animals, and in the red blood corpuscles of the embryos of mammals and birds, the division first affects the nucleus, which splits in two, each half aggregating about itself, by molecular motion, a quantity of protoplasm until the entire mass is thus divided. Such corpuscles are sometimes encountered with 1-2-4 nuclei, each of which attracts sufficient protoplasm to subsequently form a separate cell. So-called "giant cells," which play such an important rôle in rapidly proliferating structures (cancer, tuberculosis, etc.), are produced by a rapid multiplication of nuclei without corresponding division of the surrounding protoplasm.

Or, finally, the division of the cell (protoplasm) may be more lateral than uniform, protrusions shooting out from the mass of protoplasm to finally separate from the parent cell. This method of division by budding, as it is called, is mostly characteristic of the vegetable cell, but occurs also in animal cells (polyps, tape-worms, etc.), and, as a rule, in the regeneration of all cells after partial destruction of tissue. The yeast plants (torulæ) which rapidly develop in myriads in solutions of sugar, and are the immediate cause of all fermentation, are convenient objects for the study of reproduction by gemmation.

The Death of Cells.

The cell (protoplasm) having thus been born, it serves its special purpose in the animal economy, and dies. The final dissolution and disappearance of the individual cell may occur in several ways. In the first place, it may simply lose its fluid contents, dry up and desquamate, that is, be mechanically rubbed away. Such a mode of death characterises cells exposed to the open air, as the epithelium cells of the skin. Or, cells may perish from excess of fluid, be washed away and lost. This mode of death occurs in superficial mucus cells. The "rice-water" appearance of cholera discharges is due to the presence of multitudes of intestinal mucus cells, washed off by excessive drainage into the intestinal tube. Cells again may be killed by such rapid increase (proliferation) in number as to effect mutual compression and expression of their fluidity, as in the caseous degenerations of scrofula and phthisis.

But most cells die by liquefaction of their contents; conversion of their protoplasm into fat, or mucus, or water.

These substances are then absorbed from the shriveled cell wall, which, in turn, finally disappears. Lastly, the protoplasm of the cell may be substituted by the salts of lime, and, undergoing this calcareous degeneration, cease to functionate as cells. The vast majority of cells die a natural death by fatty or calcareous degeneration.

Recapitulation.

The body of an animal or plant consists, as we have seen, of a single cell, or of an aggregation of such cells. The single-celled bodies are said to be simple, the many-celled, compound bodies. These structures are, however, in essence the same; the simple bodies being simply separated further from each other. One such body (cell) depends for its existence (sustenance) upon other bodies. In the compound body, the single cells are also in a sense individual, yet they are all mutually dependent. A compound body is like a colony of ants or a hive of bees; completely isolated individuals perish. The cells in a compound body are connected together by fluid, or more or less solid, intercellular substance. The intercellular substance is the product of cells. A compound body is made up of cells and intercellular substance.

Classifications of the Tissues.

Like cells, differentiated from the rest, and grouped together for a special purpose, constitute the organs or tissues of a compound body. The body thus comes to be made up of organs and tissues, each having a special and particular purpose to subserve for the benefit of other organs and tissues as well as of itself. The body is, hence, constructed upon a plan of a division of labor; just as society is composed of farmers, tradesmen, thinkers, etc.

Anatomical Classification.

If we regard the tissues of the body simply from an anatomical stand-point, we recognize:—

1. Tissues composed of simple cells, with fluid intercellular substance, as the blood, the lymph and chyle.

2. Tissues composed of simple cells, with a small amount of solid intercellular substance, as the epithelium, nail, etc.

3. Tissues composed of simple or transformed cells cohering (in some cases), situated sometimes in homogeneous, sometimes in fibrous, and, as a rule, more or less solid intermediate substance, as cartilage, colloid tissue, adipose tissue, fibrous and elastic tissue, dentine and bone (connective tissue group).

4. Tissues composed of transformed, and, as a rule, non-cohering cells, with scanty, homogeneous and more or less solid, intermediate substance, as enamel, lens and muscle.

5. Tissues so mixed as to admit of no grouping under any of the above heads; as nerve tissue, gland tissue, vessels and hairs.

This is the histological classification of Frey.

Chemical Classification.

If we regard the body from a purely chemical stand-point, we shall have to recognize its separation into the three great classes of proximate principles:—

1. The inorganic principles; definite in their chemical composition, crystallizable, derived exclusively from without (forming to great extent the crust of the earth), subserving their special purpose in the body and then being voided from it, having undergone little or no change; as water, common salt, phosphate of lime, etc.

2. The non-nitrogenized or hydro-carbonaceous principles; which, as their name implies, contain no nitrogen, but are made up of carbon in large quantity, and of hydrogen and oxygen; principles which do not belong to the crust of the earth, but are formed exclusively in the bodies of animals and plants, where they undergo such changes as to be entirely broken up and consumed as such; as starch, the sugars and the fats.

3. The nitrogenized, albumenoid or protein bodies; indefinite in their chemical composition, containing nitrogen and mineral matters in addition to the carbon, hydrogen and oxygen, varying in consistency according to the consistence of the organ in which they are found, hygroscopic (that is, having the power to absorb water and be restored to their original consistence after desiccation), coagulable, spontaneously or artificially, and undergoing fermentation and putrefaction, by serving as food to microscopic animals and plants, which split up their chemical combinations into new compounds (alcohol, carbonic acid gas, water and other products of decomposition), principles also formed exclusively in the vegetable or animal cell and undergoing entire change in the body. Examples of this class of proximate principles, which includes also the coloring matters and certain crystallized products of excretion, are albumen, fibrin, casein, myosin, pepsin, lecithin, hæmoglobulin, urea, etc.

This is the chemical classification of Robin and Verdeil.

Physiological Classification.

If, however, we regard the construction of the body from a purely physiological stand-point, we shall have to separate the tissues into classes according to pre-eminence in especial properties, with all the rest of which each one is endowed in subordinate degree, as :—

1. The tissues eminently mechanical; bone (including teeth), outside layers of epithelium (including hair and nails).
2. The tissues eminently contractile; the muscles.
3. The tissues eminently irritable; the nerves (and nerve-centers).
4. The tissues eminently secretory (including excretory); the digestive, genito-urinary, pulmonary, etc., epithelium.
5. The tissues eminently metabolic (elaborative or transformative); the gland cells.
6. The tissues eminently reproductive; the ovary and the testis.

This is essentially the classification of Michael Foster.

A study of these three methods of classification gives a clear survey of the construction and action of the various tissues in the body, whether simple or complex. These properties and actions in the simplest forms of protoplasm, like the amœba, are very few and very limited. Under favoring conditions and in many millions of years, aggregated masses of protoplasm build up the most complicated structures. At various periods in the history of our earth,

> "In days of yore, no matter where or when
> Before the low creation swarmed with men."

different animals have successively held the dominant place. At the present time the highest and most complicated structure is the body of man. But the principles of construction, the general properties of composition, remain everywhere the same. What is true of the monad, is true of man. The binary compounds of inorganic matter, carbonic acid gas (COO), and water (HHO), are raised in organic matter to ternary compounds, starch, etc. (CHO), and upon the question whether this rearrangement of elements happens naturally, *i. e.*, chemically, or supernaturally, rests the most momentous problem of our day.

LECTURE VIII.

BONE AND ITS PROPERTIES.

CONTENTS.

Anatomical Dignity of Bone—Relation of Bone to Nerve Tissue—The Skeleton—The General Properties of Bones—The Histology of Bone—The Haversian Canals—The Lamellæ—The Bone Corpuscles and Lacunæ—The Canaliculi—The Chemistry of Bone—Difficulties Attending the Study of Osteology—Bones as Fuel—Gelatine as an Aliment—The Resistance and Resilience of Bone—Constancy of Chemical Composition—Rachitis and Osteo-Malacia—The Phosphate of Lime—The Preservation of Bone—Bone a Connective Tissue—The Formation of Bone—The Periosteum—The Centre of Ossification—The Determination of Age—The Femoral Epiphyseal Centre—The Excavation of Bone—Air in Bone—The Marrow—Studies in Living Bone—Bone as a Symbol of the Body.

The Anatomical Dignity of Bone.

Bone has a structural dignity which is attained, with one exception, by no other hard or solid formation in the economy of nature. The existence of true bone in the body of an animal brings it to rank at once among the class of vertebrates. Wherever is bone, is a spinal column. The hard parts of all invertebrate animals are made of horn and shell, never of true bone. Even the teeth, which alone among other solid structures enjoy the same exceptional place, from the stand-point of comparative anatomy, could not be present at all, were it not for the fact that their roots are incrusted with a layer of bone, the cement, whose periosteum fusing with that of the alveolae of the bones of the jaws, secures their fixation in the body.

Relation of Bone to Nerve Tissue.

For the bone in the spinal column of the vertebrata stands in the most intimate relation to the great chain

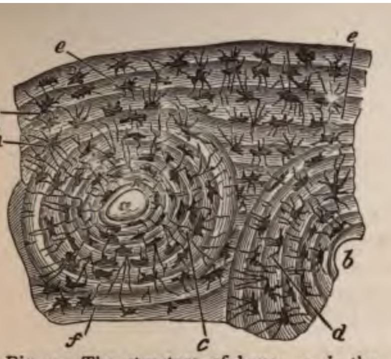

Fig. 21.—The structure of bone. *a*, *b*, the Haversian canals. *c*, *d*, the Haversian lamellæ. *e*, *e*, periosteal lamellæ. *f*, *g*, the bone cells and canaliculi. (p. 153-156)

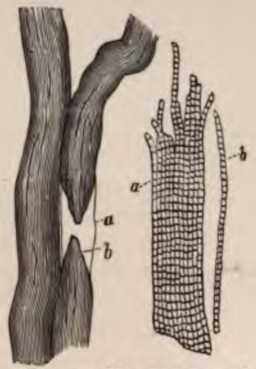

Fig. 22.—The structure of striped muscle. *a* (left figure), sarcolemma. *b*, end of ruptured fibre. *a* (right figure), transverse striæ. *b*, fibrilla. (p. 178-179)

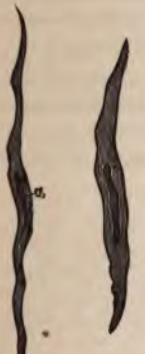

Fig. 23.—Involuntary (smooth) muscle fibre. *a*, nucleus. (p. 182)

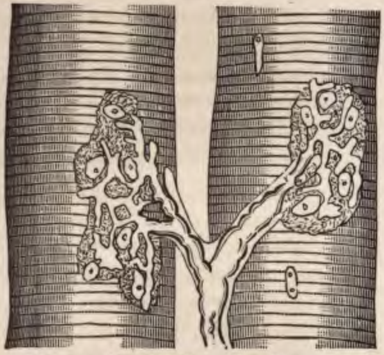

Fig. 24.—Termination of motor nerve in voluntary muscle. The muscle fibres exhibit the striæ and sarcolemmar nuclei; the nerve, its constituent parts and the terminal plates. (p. 231)

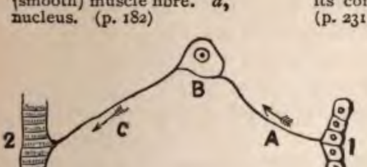

Fig. 25.—Schematic representation of reflex action. 1, sensitive (epithelial) surface. 2, motor (muscular) structure. *A*, afferent (sensitive) nerve; *B*, nerve cell; *C*, efferent (motor) nerve. (p. 237)

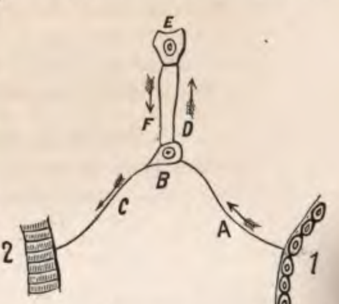

Fig. 26.—Schematic representation of volitional action. 1, sensitive surface. 2, motor structure. *A*, afferent nerve; *C*, efferent nerve; *B*, nerve cell (for simple reflex action). *D*, afferent nerve; *F* efferent nerve; *E*, nerve cell (for volitional action). (p. 238)

The Structure of Bone and Muscle, and the Modus Operandi of Reflex Action.

of nervous matter, the spinal cord, which it encloses and protects. Each vertebra corresponds to, and is developed in connection with, one of the primitive ganglia of the nervous system. Above it and below it emerge the spinal nerves. So that a vertebra has been defined to be "a bone or axial segment of the skeleton included between two pairs of nerves." The subsequent growth of the column, however, faster than the cord, disturbs this topical relation so that the cord which at the third month of intra-uterine life reaches as low as the end of the sacrum, if not to the coccyx, stops short in the adult at the second lumbar vertebra. The spinal nerves then come to pass down from the cord and out through the intervertebral foramina with such a degree of obliquity, increasing from the first to the last pair, that it would seem as though the cord had been drawn upwards, bodily, within the spinal canal.

The Skeleton.

The bones of various shape and size, jointed together in various ways, constitute the skeleton or scaffolding, whose disposition determines the size, shape, posture, in short, the configuration and habitus of the animal:—*Ossa autem corpori humani formam, rectitudinem et firmitatem conciliant* (Galen).

The word skeleton is often said to be derived from σχέλλω, to dry up, in the sense in which this term was used by Herodotus who speaks of the *sole aridum et exsiccatum cadaver*, which the Egyptians exhibited at their festivities, with the greeting, *edite et bibite, post-mortem tales eritis!* Skeleton is more probably derived from σχέλος, thigh bone, which, as the largest bone in the body, had its name used as a designation for the whole structure (Hyrtl).

In the crustacea, molluscs and in insects, the skeleton, of shell or horn, is on the exterior of the body. The first example of internal skeleton is met in the cephalopodous molluscs in which certain cartilaginous plates are inclosed in the body of the animal protecting certain parts of the nervous system.

General Properties of Bones.

The elongated, tubular, bones of the extremities serve as levers for the muscles, to the action of which, by their restriction of movement, they lend precision and effect. Hence the bones are often mentioned as the passive organs of locomotion. Spread out in surfaces, more or less flat, or stretched out in rods, more or less flexible, they form cavities, the skull; or basins, the pelvis; or cages, the thorax, for the protection and support of the softer organs. Broken up, as it were, into smaller fragments, with irregular surfaces and spongier structure, often with intercalated cartilaginous pads, they act as bumpers or cushions to break the force of shocks, as at the wrist and ankle and in the spinal column. Contracted in their shafts, or alternately convex and concave in their course, as in the long bones and vertebral column, they give space for the origin and lodgment of muscles, and support to the heavier organs, and expanded at their ends, they widen the surface of articulation, afford room for the insertion of ligaments and tendons, and furnish fulcra for the action of the muscles, by distancing the point of insertion from the centre of motion. Increased in weight and size near the trunk, they give momentum and range to the movements of the body, and abbreviated in all their dimensions at their distal extremities, they lend celerity and accuracy to its various actions. They are thickened into massive bars and plates as in the pubes and ilium, thinned down to papyraceous sheets, or rolled up in delicate scrolls as in the nasal fossæ, projected in vast promontories in the various tuberosities, or reduced to insignificant fragments as in the bones of the ear, all for purposes familiar to every student of anatomy.

The Histology of Bone.

The microscopic appearance of bone is characteristic. For bone belongs, histologically, to the group of the connective tissues and hence consists, primarily, of a network of stellate ramifying cells (bone cells, bone corpuscles, corpuscles of Purkinje, etc.). In the subsequent process of ossification these cells desiccate and leave spaces, lacunæ, filled with serum or air (carbonic acid gas). The hardness of bone is due to the deposit of various mineral salts, principally of lime, in the intercellular spaces. Any doubt as to the nature of a substance is at once resolved under the microscope, so far as bone is concerned, at a single glance.

The distinguishing characteristics of bone are four, viz., First,

The Haversian Canals.

These canals are the conduit tubes for the bloodvessels, the main trunks of which penetrate the surface of the bones at the so-called nutritious foramina. Reaching the interior of the bone, the canals ramify throughout its substance, varying in size from $\frac{1}{80}$–$\frac{1}{500}$ of an inch (0.1128–0.0149 mm.) in diameter, so completely supplying all parts of it, that no osseous tissue is removed from its nutrient blood at a greater distance than the $\frac{1}{170}$ of an inch. The abundance of the blood supply to bone imparts to it a pinkish hue, though the fundamental color of bloodless bone is a pale gray, except in some fishes where it is green. Bone, like all other vascular structures, is liable to inflammations, and wounded bone bleeds. In cross sections of bone, the bloodvessel canals, called also the

Haversian canals, to perpetuate the name of their discoverer, Clopton Havers (1691), appear as rounded or ovoid openings of various size, in long sections as split canals.

Where the bone tissue is so thin that it may be directly nourished by the vessels in the two enclosing layers of periosteum, as in the laminæ papyraceæ of the ethmoid bone and in the translucent regions of the palate and lachrymal bones, and in the leaves of spongy tissue every where, Haversian canals are not developed. In the flat bones of the cranium, etc., and in the sternum, the Haversian canals radiate in stellate form from definite points (from the tuber frontale, parietale, etc.).

Second,

The Lamellæ.

Bone tissue is deposited in layers, 6–15 in number, each about $\frac{1}{3000}$ of an inch (0.0065 mm.) in diameter, about the bloodvessels, the oldest layers being, like geological strata, the deepest, that is, nearest to the vessels. Or, the layers are formed from the under surface of the periosteum and thus encircle the entire bone. As the bone continues to grow, the relation of these layers to each other, of course, undergoes change. That is, they appear to abut against each other like the upheaved volcanic strata of the earth against the horizontal aqueous strata. The Haversian lamellæ lie concentrically about the bloodvessel canals, and as these canals in the long bones run, for the most part, parallel with the long axis of the bone, the Haversian lamellæ form series of columns about each other throughout the length of the bone, connected with each other, braced, as it were, by the lateral columns about the lateral anastomosing canals.

A singular system of lamellæ first described by Sharpey (1856), as perforating bone fibres, pass from the under surface of the periosteum downwards through the circular periosteal layers "like nails through the leaves of a book, pinning them together." They are found in human bone as well as in that of other mammals, but more frequently in amphibia and fishes. They are the residue of the connective tissue substance, the original matrix of bone, and hence are not found among the Haversian canals.

Third,

The Bone Corpuscles,

corpuscles of Purkinje (1834), or rather the lacunae, the spaces left after disappearance of the corpuscles.

These lacunæ, ovoid, and with their radiating canaliculi, stellate in shape, are seen profusely scattered about in the microscopic field (Harting counted 910 in a square millimeter of bone), lying between or in the various lamellae. They measure from $\frac{1}{1250}$–$\frac{1}{800}$ of an inch in their long diameter by about $\frac{1}{2300}$ of an inch in width. (0.0181—0.0514×0.0068 mm.). The lacunae (λακος, lake), as already intimated, are the open spaces filled with serum, in dried bone with air, representing the sites of the original bone (connective tissue) cells. In the process of ossification, mineral matter comes to be deposited about the bone cells, which finally disappear, leaving the lacunae as moulds indicating their former site and size. The original bone corpuscles (protoplasm) or cells, with their elongated nuclei, may only be obtained from fresh (growing) bone whose mineral matter has been dissolved out by hydrochloric acid.

Fourth,

The Canaliculi.

These are the minute wavy canals which make communication between different lacunae, between lacunae and Haversian canals, and between lacunae and the general medullary cavity (the marrow). They merit the diminution appended to their name, as they measure but from $\frac{1}{800}$—$\frac{1}{600}$ of an inch in length and $\frac{1}{25000}$ of an inch (0.0514×0.0008 mm.) in width. Whether the contractile bone protoplasm protrudes filiform processes into these tubes, or whether they permit to circulate in their interior, nutritive juices to ultra-vascular parts, are questions still unsettled. That they may serve as communicating tubes is proven by the appearance of mercury in numberless points upon the surface of bone after its insertion into the medullary cavity. Gerlach succeeded in injecting bone with various coloring and hardening substances in the same way.

These are the four distinguishing characteristics of bone. Any tissue which does not exhibit them under the microscope, however analogous in all its properties, as the ivory or the dentine of the teeth, is said not to rise to the anatomical dignity of true bone.

The Chemistry of Bone.

Bone has been repeatedly analysed by the most expert chemists, and though the results obtained have differed in unimportant details, on account of the difficulty of freeing its tissue from substances (fat, blood, etc.), with which it is intimately commingled, the general conclusions remain about the same. Thus bone is found to be composed of two-thirds mineral and one-third animal matter, as the following table, deduced by Lehman from the best analyses, exhibits:

Composition of Bone.

Phosphate of Calcium, - - - - - - -	57
Carbonate of Calcium, - - - - - - - -	8
Fluoride of Calcium, - - - - - - - -	1
Phosphate of Magnesium, - - - - - - -	1
Mineral matter, - - - - - -	67
Animal matter, - - - - -	33
	100

The mineral may be readily separated from the animal matter by maceration of the bone in dilute hydrochloric acid. The size and shape of the bone remains perfectly preserved by the animal matter left, which, however, is so soft and pliable that long, slender, bones, like the clavicle or fibula, may be tied in knots, or flat bones, like the scapula, crumpled in the hand.

The animal matter may be likewise destroyed while the mineral matter remains. When a bone is subjected to sufficient heat in an oven to drive off (decompose) animal matter, the bone first turns black from the carbon deposited on its surface. The carbon is subsequently volatilised (oxidised), however, escaping as carbonic acid gas, leaving only the white bone ash. Though the size and shape of the bone are still preserved in every particular, the cohesion of its particles is nearly destroyed, the whole structure crumbling away on the slightest touch. The bones in the ancient catacombs are thus wholly, or in part, reduced by the gnawing tooth of time.

Difficulties Attending the Study of Osteology.

If bones be exposed to the air and sun during this process of reduction, they gradually dry up and bleach to the color and consistence of their mineral constituents. It was only from such specimens, rejected by the Tiber, or found upon the battle-fields of slaughtered Germans, that the ancient Romans could prosecute their studies in osteology. What bones escaped cremation with them had to be religiously consigned to putrefaction in the earth. Galen was compelled to travel from Pergamos to Alexandria to see a perfect skeleton. It is highly probable that he never opened a human body, as his descriptions of organs are only those of the ape and dog. "The age in which he lived, says the historian, offered, yearly, thousands of human lives to the caprice of the Roman people, and their cruel Emperor even cast them as prey to the wild beasts of the Coliseum, but would not grant one single dead body to the study of science" (Hyrtl).

Bones as Fuel.

So long as the animal matter of bone remains, however, it is, of course, combustible, and is even used as fuel in places where ordinary fuel is scarce. Thus in the Falkland islands, where trees are few, the inhabitants roast the flesh of cattle upon fires made from the bones mixed with turf, and Darwin, in his Voyage Round the World, relates that the Guachos in South America, where there was very little brushwood for fuel, soon made, to his great surprise, a fire nearly as hot as coals, from the skeleton of a bullock lately killed, whose flesh had been picked away by the carrion hawks. They told him that in winter they often killed an animal, cleaned the flesh from the bones with their knives and then with these same bones roasted the meat for their suppers.

Gelatine as an Aliment.

When bone is boiled with water, its animal matter is converted into gelatine, proof that bone cartilage is not common cartilage, which, when boiled, yields chondrin, a very different substance. Though the gastric juice will attack and dissolve gelatine, it has very little, if any, nutritive properties, and should never, in any of its forms (jellies, isinglass, Iceland moss), be relied upon as an article of diet. It has the semblance only, not the substance, of food. The gelatine and the marrow having been extracted from ingested bone, the mineral matter escapes with the feces. Such hard, white, feculent, matter from the dog was administered as a remedy to epileptics in old times, under the classical name of "Album Grecum." It is a subject for congratulation that the therapy of this disease has been somewhat improved since then.

The Resistance and Resilience of Bone.

The proportions in which the animal and earthy matter are united in bone endow it with its peculiar combination of properties, resistance and resilience. Bone has twice the resisting force of solid oak and nearly three times as much as ash or elm. The elasticity or resilience of bone, aided by the cartilaginous structures to which it is attached, enables it to greatly economise muscular force. For example, the return of the thorax after inspiration, that is, the whole force of tranquil expiration is effected by the elasticity of the ribs and cartilage, and the deflected spinal column resumes its original position in the same way with the ease and grace of motion observed in a bent spring when the force has been relieved. Bone resilience is readily demonstrated on the skeleton by the force required to hold the fibula against the tibia. When the clavicle, detached and held at a right angle to a hard surface, is struck upon the end with a hammer, it will rebound to a distance of two feet or more. The equal and much greater concussion, often received upon various parts of the body, is dissipated and lost, on account of the elasticity of bone, before reaching the delicate organs enclosed. The relative resistance and resilience of bone is exhibited in the experiment of Bloan, who found that a square inch of it (cross section) only broke under a load of 368–743 hundred-weight, while a square inch of copper rod gave way under 340 and of Swedish wrought-iron under 648.

Constancy of Chemical Composition.

So admirably are the organic and inorganic matters blended in bone to secure the properties and subserve the purposes required, that any variation in their proportions in the different bones of the same animal, or at different periods of life, or even among different animals, is exceedingly small. There is a little more earthy matter in the long bones of the extremities than in those of the trunk, and a little more in the larger bones of the extremities than in the smaller, but the increase is very slight and is in no way proportioned to the density or hardness of bone, which is determined solely by the compactness of its tissue. Thus the flexible, semi-transparent, easily divided, bones of the fish contain as large a proportion of earthy matter as the ivory-like leg bones of the deer or sheep. Bibra found the proportions of animal and earthy matter, contrary to the statements usually made, very nearly the same in the bones of the fœtus of seven months, in those of a man of thirty and in those of a woman of seventy-eight, and Dr. Stark concludes from his numerous analyses "that the amount of earthy matter in healthy bones is nearly uniform over the whole animal kingdom; and that neither the solidity or sponginess, the rigidity or flexibility, the opacity or transparency of bone depends on an increased or diminished amount of the earthy matters in its composition." It is this constancy of composition which justifies the belief that the union of the animal and earthy matters is not mechanical, but chemical.

The differences in the bones at different periods of life, usually ascribed to variations in the amount of earthy matter, depend entirely upon variations in the amount of bone substance, not at all upon variations in its physical construction. A fœtal bone is just as dense and as hard to cut with a knife as an adult bone; it is more flexible simply because there is less of it. It is the difference between a little stick and a big stick of the same wood. The child's bones are lighter in correspondence with its nimble and incessant movements, the bones of the adult are heavier and stronger in correspondence with the force of his muscles, and the old man's bones are lighter again in correspondence with his slower and more cautious movements. But the difference is entirely due to the deposition and absorption of bone matter in correspondence with the general nutritive force. A fracture of a child's bone unites more rapidly and of an old man's bone more slowly, not because of more animal matter in the child and less in the old man, but because of the high activity of nutrition in youth and its gradual failure in advancing age. The difference in the strength of bone thus induced in the physiological decay of age may be made manifest by direct experiment. Thus a prism from a cross section of the fibula in an adult aged 30 breaks under a weight of 33 lbs. (15.03 kilogrammes), while the same sized prism from the same bone in an old man aged 74 breaks under a weight of 9½ lbs. (4.33 kilogrammes).

Rachitis and Osteo-Malacia.

There are, however, certain diseased conditions which very greatly disturb the proportions of animal and earthy matter in bone, and thus lead to most disastrous deformities. In rachitis (rickets) and osteo-malacia, for instance, both the phosphate and carbonate of lime are often reduced to less than a quarter of their usual quantities. In rachitis, the mineral salts are withheld from the bone in the blood. In osteo-malacia, these salts were originally deposited but have been subsequently absorbed. Great care has to be exercised with rachitic children, as the bone yields to every pressure. Disfigurations of the head ensue from too long decubitus in one position, and deformities of the pelvis, such as in after-life may greatly embarrass the accoucheur, result from too long support of the child in one posture upon the arm of the nurse. Fortunately, this disease, which is an expresanimal and mineral matter. Thus Davy found in the tooth of a mammoth 30.5 parts animal to 69.5 mineral matter.

Bone, a Connective Tissue.

Notwithstanding its great importance, bone does not belong to the primary or original tissues of the body. Many of the remaining tissues are far advanced in development before bone puts in any appearance at all. Bone belongs to the group of connective, or, as Kölliker has better put it, the "sustentacular" tissues, but a subsequent transformation or elaboration of this tissue is required to develop bone. As any connective tissue may ossify, bone sometimes appears in strange and unwonted places. The skin, the fibrous membranes (dura mater), the tendons, the sclerotic coat of the eye, are naturally partly bony or contain bone in some of the lower animals and bone not unfrequently presents in these structures in man. Thus my colleague Dr. W. W. Seely exhibited to the Cincinnati Academy of Medicine an eye-ball which he had removed, containing a capsule of bone covering the entire inner surface of the choroid coat of the eye and referred to a case on record in which there was a complete globe of bone covering the choroid and extending across behind the lens. Most melancholy are the cases of so-called myositis ossificans progressiva, in which the inter-muscular connective tissue is converted into true bone, locking up the action of the muscles as fatally as in the fabled metamorphoses of Ovid. Cases of this terrible disease has been put upon record by Rogers, Henry, Skinner and Nikoladoni and our demonstrator of anatomy, Dr. Ransohoff, gives in detail in a recent number of The Lancet and Clinic an account of a case which fell under his personal observation, where "the process of placing the patient on his feet involuntarily suggested that of placing a statue upon its pedestal." Most of the cases of so-called ossifications of soft parts, however (as in the larynx, the heart, etc.), turn out to be simple calcifications (infiltrations with mineral salts), a very inferior process to the development of true bone.

The Formation of Bone.

For the most part, bone is formed from cartilage. It is more true to say that bone is formed in cartilage, for the cartilage that is to result in bone must entirely disappear before bone tissue can develop. The inter-cellular spaces in cartilage dissolve away, leaving medullary canals, and the cartilage cells become enclosed in lime salts (calcified) as the first step in the process of ossification. Then the calcified cartilage itself undergoes liquefaction and young formative cells (probably lymphoid cells of the blood), emigrated from advancing bloodvessels, penetrate the cartilage cavities to become, some of them at least, generators of the osseous tissue. These "osteoblasts," as they are now called; later, they are the stellate bone cells; secrete from their interior a thin layer of homogeneous, opalescent matter, which is subsequently infiltrated with the salts of lime, to constitute the first layer (lamella) of true bone tissue. A repetition of this process produces the successive layers or strata of bone about the bloodvessels, now known as the Haversian canals.

The vessels in the membrane enveloping bone, the periosteum, which is at first highly vascular, likewise furnish osteoblasts for the development of successive layers of bone about its circumference.

There is, however, some exception to the rule that bone is moulded first in cartilage. For the flat cranial bones, the upper and lower jaw, the nasal, lachrymal and palate bones, the vomer, zygoma and finally the inner leaf of the wings of the sphenoid and the cornua sphenoidalia, in short, many of the bones of the face and all the bones of the head (except the base of the occipital bone, which is often described as a separate bone belonging to the spinal column), develop from membrane, that is, from the periosteum or pericranium in the site of the future bone. In all cases, however, the process is essentially the same.

So active is the power of the periosteum in the production of bone that the endeavor is always made by the surgeon to save it as much as possible in exsections of dead bone tissue. Great masses of bone, the entire clavicle for instance, may be reproduced, if the under (generating) layer of periosteum be left uninjured. Indeed, Ollier has found that pieces of periosteum transplanted from one part to another or from one animal to another will beget bone even in places where it must be regarded as a foreign body.

The Periosteum.

The bones, thus, do not lie naked in the body. They are all clothed with a dense fibrous membrane, the periosteum, which, in the first place produces the bone tissue, or reproduces it after injury, from its under surface, and then, thickening as the bone develops, isolates and protects it from circumjacent tissues. The periosteum thus acts as a barrier against the invasion of disease. The shin bone, for instance, is long protected against damage from the so frequent and so extensive ulcers of the leg. In cases where the periosteum is scant or insufficient to cover the entire surface, superficial inflammations easily dip down to involve the underlying bone. That the slightest wounds or contusions of the ends of the fingers may extend to the insufficiently covered bone beneath is proven by the frequent occurrence of those painful affections known as whitlows or, with us, as felons. Hence the advantage of free and early incision in their treatment to permit escape of the products of inflammation. Lastly, the periosteum is a surface sheet of fibrous tissue wrapped, as it were, about the bone to give firm origin and fixed insertion to muscles, ligaments and tendons.

The Centre of Ossification.

The point at which the osteoblasts begin to form and from which the bone-making process irradiates to the whole structure is known as the "centre of ossification." But the period of time at which this centre appears does not at all correspond to the deposition of the primordial cartilage in the site of the future bone. Thus the cartilage of the vertebræ, the so-called notochord or chorda dorsalis, appears in the earliest days or weeks of development, while the first points of ossification show themselves about the beginning of the second month almost simultaneously in the clavicle and lower jaw.

The Determination of Age.

As the exact period of time in which ossification commences in the various bones, and the rate at which it advances, have been definitely ascertained, it may be readily understood that we possess in such data the means for accurate estimate of the age of the bones or of the body. Beale has discovered that immersion of the body of the fœtus, or the new born child, in alcohol and soda (8 to 10 drops of solution of caustic soda to the ounce of alcohol) renders the soft parts so translucent or transparent, without affecting the earthy matter, that the stage of ossification in the different bones becomes at once visible to the eye.

Or the age may be determined by the size or length of the bones. Günz has carefully prepared for this purpose a table of the dimensions of the various bones at birth.

The Femoral Epiphyseal Centre.

But the readiest method of deciding the question of maturity at birth, a question of great importance from a forensic point of view, was first established by Béclard, and subsequently elaborated by Ollivier, Hartmann and Mildner. These investigators found that the most reliable sign of an advanced process of ossification was the presence of a "centre" in the lower end (epiphysis) of the femur. This centre develops in the second half of the last month of pregnancy, before the existence, thus, of any epiphyseal centre in any other long bone of the body. Section of the epiphyseal cartilage of this bone discloses to the unaided eye, in the centre of the milk-white, cartilaginous, mass, a more or less circular, bright, blood-red, disk, whose density easily distinguishes it as bone in the softer tissue about it. The comparative imperishability of bone makes this sign all the more valuable, as it may always be discovered though decomposition of the remaining structures shall have been far advanced. In such cases it loses its bright red color, becoming of a dirty yellow hue, but it still stands prominently forth and differentiates itself from the surrounding decomposing, reddish, matter by its color and its hardness. Once seen, it will be always recognised again. In very small bones, it must be hunted out with a lens, but in bones of average size, it is plainly visible to the eye. Liman states, as the result of 620 observations, that the presence of this nucleus of bone, with a diameter of over nine millimetres (4 lines), is the most unmistakable proof that the child was born mature. A less diameter (3 lines) would, of course, not disprove maturity at birth, as the bones in some individuals are unusually small. Cases are narrated by Liman and Ollivier where decomposed and mummified parts only were found, and yet maturity at birth was thus established.

The Excavation of Bone.

As bone grows upon its exterior it is absorbed from the interior of its mass. This process of interior absorption occurs in all bones alike, regardless of their size, or shape or use. Thus the bones, in all cases solid at first, become hollowed out inside. In the long bones, a great cavity (the medullary cavity) results, in the flat and irregular bones, a multitude of small communicating chambers. This spongy or cancellated tissue left by the absorption of the bone has, of course, the same texture and composition as the still compact external layer. But its physical properties differ. That is, it is lighter and softer, and hence is better fitted to resist and disperse force. Yet the whole bone loses, in this loss of substance, little or none of its strength. For the long bones are thus converted into tubular structures, and every one, familiar with mechanics, is aware of the greater strength of the same amount of substance arranged in tubular over that in solid form. The flat bones, as in the cranium, become, thus, three tables, of which the outer and inner are compact, and the central, the diploe (from *δια, πλεω* to fill through, not from *διπλοος* double), is spongy tissue. The excavation of bone tissue in this way, the stuffing of it, as it were, with resilient tissue, aided, of course, by the general arched form of the bone, so disseminates, lateralises and absorbs shocks, in the case of the cranium, for instance, that the brain is seldom injured by a force insufficient to crack the skull. The irregular collection of seven or eight obliquely moulded, soft, bones at the wrist and ankle, bound so firmly together by ligaments as to practically be one bone, and yet movable enough to permit wide range of motion, is an admirable example of the advantage of cancellated structure in dissipating shocks as received upon the hands and feet. The jaw bones, at their free edges, would be chipped away under the chopping and grinding action of the teeth, were it not for the cushion of spongy tissue (the alveolæ) in which the teeth are embedded.

But this interior absorption of bone does not occur in a hap-hazard way. If a long bone, for instance, be split in two, lengthwise, it will be seen that the spongy tissue is arranged in a definite manner, that is, that the individual layers of bone, thus resulting, run in definite directions. Such directions are most markedly manifest about the heads and extremities of the long bones. The interior plates here form pillars, arches, buttresses, braces, so constructed as to most effectually receive and transmit weight from the articular surfaces to the compact tissue of the shaft. This architecture of bone, as it is called, has received able exposition at the hands of a number of observers, Wolfmann, Meyer, and others, in terms of highest admiration. Indeed, the internal architecture of bone was at one time triumphantly singled out as an evidence of design in creation. It is hardly necessary now to state that natural selection achieves, in the courses of ages, the highest order of design.

Air in Bone.

The excavation of the interior of bone secures to bones their lightness. Hence it meets its highest expression in birds, where the number of bones into which air is admitted is directly proportionate to the powers of flight. When the trachea is tied in some birds, respiration may be sustained for a time through an aperture made in the arm (wing) bone. Thus, in the swift, air finds its way into most of the bones; whereas in the ostrich and its allies, the shafts of the long bones are partly occupied by spongy tissue, and in the apteryx, none of the bones receive any air at all (Humphrey). In fishes, supported as they are, by water, all the bones are solid, as they are during the aqueous (intra-uterine) stage of life in man. The facial bones in all mammals (including man) are mere shells filled with air for the sake of lightness. The suppression of these bones in man to give range and prominence to the higher organs of sense, and their comparative lightness are distinguishing characteristics of the human skull and skeleton to secure the *vultus ad sidera.*

The Marrow.

The next lightest medium to air is oil. Hence we find the bones of most land animals filled with liquid fat. The long bones of the adult contain a marrow of which 96 parts are oil. Large reservoirs are thus inserted in the body, of this highly nutritious substance, upon which draft is made in insufficient alimentation or inanition from any cause. The quantity of oil present in the bones is thus indicative of the health and vigor of the body; hence the force of the comment of Job upon a man in the prime of his strength, "his bones are moistened with marrow." Timon of Athens says "consumptions sow in hollow bones of man," and Lucio (Measure for Measure) remarks upon the effects of chronic syphilis in the accusation "thy bones are hollow; impiety has made a feast of thee." It has occasionally happened, as an anomaly of development, that this process of internal absorption of bone has not taken place. The bone then remains solid (compact) throughout. The celebrated anatomist of Holland, Frid. Ruysch, is said to have possessed a fork whose handle had been turned from a solid human bone.

Studies in Living Bone.

In our studies of bone, dead and dried, as in anatomical specimens, we are apt to forget that bone in the body lives. Bone is as much alive as brain or blood. It absorbs, breathes, secretes and reproduces itself like every other living tissue. It has been shown by Ollier that so long as bone tissue retains its vitality, it may be removed from one animal to another, or be transplanted to various parts of the same animal, and not only continue to live, but also increase in bulk.

The absorptive power of bone is elegantly exhibited by feeding animals with coloring matter having an affinity for the phosphate of lime. It was long ago accidentally discovered by Belchier that madder fed to pigs imparts its color to the bones. If the animal be very young, the whole skeleton may be thus colored in a single day. In older animals, the coloration is more slow and less perfect, only the growing parts of the bone, as at the ends and surface, assuming color. Periodically administered and withheld, it produces alternate layers of red and white. Belchier first used this agent as a means of studying the growth of bone, and Tomes prepared beautifully colored specimens in this way. That long bones grow in length only at the ends, after ossification of the shaft, was conclusively proven by the experiments of Hales and Hunter, who inserted into the shafts metallic substances, certain distances apart, and found, after an interval of time, that the distance between them remained the same, while the extremities of the bones were much further apart. And that bone grows upon its surface and is hollowed out in its interior, was as conclusively proven by du Hamel, who put a silver ring on one of the long bones of a pigeon, and found it later in the medullary cavity, which had the same diameter as the ring.

Use and disuse exercise the same influence upon bone as upon other living tissues. Bones increase both in thickness and length when called upon to support heavier weights. Different occupations vary the size of the bones in all directions. These variations are exemplified in the osseous changes manifesting themselves upon the domestication of wild animals. The leg bones, under conditions of security and plenty, greatly increase in size, while the wing bones diminish. The legs of sailors employed in the late war were longer by 0.217 of an inch than those of the soldiers; though the sailors were, on an average, shorter men; while their arms were shorter by 1.09 of an inch, and therefore out of proportion shorter, in relation to their lesser height. Rengger attributes the thin legs and thick arms of the Payaguas Indians, to successive generations having passed their whole lives in canoes with their lower extremities motionless. Darwin, in his Descent of Man, from which work these examples are cited, gives abundant evidence exhibiting the changes occurring in different bones under different conditions. Thus in long-eared rabbits, even so trifling a cause as the lopping forward of one ear, drags forward on that side almost every bone of the skull; so that the bones on the opposite side no longer strictly correspond. The life of bone is strikingly shown in the absorptive changes which ensue upon long continued pressure. The flat heads of Indians, short feet of Chinese, and bent ribs of more civilized races, are all proofs of the yielding of bone under distorting pressure. Not very long ago, a case was reported in Vienna, where a young girl died of inflammation of the brain caused by the long continued and gradually tightening pressure of an elastic cord used to confine a net for the hair. The cord had absolutely cut through the cranium to the brain.

Quite recently, M. Ollier has shown that it is possible, by irritating the ends of bones, or the periosteum upon their surface, to greatly alter their size and shape. We may thus secure, he claims, a harmony of development between two parallel bones, on the one hand, by increasing the activity of development of the bone in arrears, on the other, by retarding or checking the development of the bone in excess.

Nothing, however, has so much elevated the physiological dignity of bone as the recent revelations of Neumann and Bizzozero, to the effect that a vast number of the blood corpuscles, the most essential element of this most essential fluid, are developed in the marrow of bone. These observers have discovered in the marrow all the transition forms between the white lymph corpuscles and the red blood corpuscles, so that bone comes to rank with the liver and the spleen as one of the cradles in the rearing of the blood.

Bone is often used as a symbol of the whole body. "Flesh of flesh and bone of bone" is the phrase used to express the intimacy of the conjugal union. Was not from a rib in the same symbolic sense developed the whole female body? Schiller says jestingly:—

"Behandelt die Frauen mit Nachsicht!
Aus krummer Rippe war sie erschaffen,
Gott konnte sie nicht ganz grade machen,
Willst du sie biegen, sie bricht."

(Handle a woman with care!
She was made from a crooked rib,
God could not make her perfectly straight,
If you bend her, she will break.)

But it was reserved for M. Frederic de Rougemont, a distinguished theologian, to solemnly announce a satisfactory reason why "God in his infinite wisdom selected the rib in preference to any other bone of Adam's body." He says: "He took no piece of the head—woman would then have had too much intelligence; He took no piece of the legs—woman would then have been too much on the move; He took a piece near the heart, that woman should be all love!" Gretchen sings in her utter desolation:

Wer fühlet
Wie wühlet
Der Schmerz mir im Gebein.

(Who feels, how rages, the pain in my bones.)

Agamemnon (Troilus and Cressida) is addressed:—

> "Thou great commander, nerve and bone of Greece."

and when Achilles, later in the same play, wished to express in the death of Hector, the total overthrow of Troy, he exclaims:

> "Now Troy sink down,
> Here lies thy heart, thy sinew and thy bone."

LECTURE IX.

MUSCLE AND ITS PROPERTIES.

CONTENTS.

Etymology of Muscle—Muscular Motion—Striped and Smooth Muscle—The Color of Muscle—The Anatomy of Voluntary Muscle—The Sarcolemma—The Muscle Fibre—Muscle Protoplasm—General Properties of Muscles—Names of Muscles—Form and Shape of Muscles—Smooth Muscle—Disposition of Smooth Muscle—The Chemistry of Muscle—The Reaction of Muscle—Specific Properties of Muscle—The Elasticity of Muscle—The Tonicity of Voluntary Muscle—Tonicity, a Reflex Phenomenon—Tonicity of Involuntary Muscle—The Sensibility of Muscle—Sensibility and Sensation—The Sensation of Fatigue—The Exercise of the Muscular Sense.

Etymology of Muscle.

The muscles are the active organs of motion. The word bone (Saxon, ban; Swedish, ben; Danish, been; German, bein), means something set or fixed. The word muscle (Latin, musculus) originates, according to some etymologists, from μυς, a mouse or rat, because the ancients compared the muscles to flayed rats or mice, but is more probably derived from μυειν, to move, motion being the most striking and distinguishing property of this tissue. Brawn, an old English synomim of muscle, expressed the fact that the bulk and strength of the body was expressed or made manifest in its flesh or muscle.

Muscular Motion.

Though the mere existence of motion can not, as once taught, be accepted as a point of differentiation between animals and plants, because it is a protoplasmic endowment common to both, nevertheless a high degree of it and a ready exhibition of it does distinguish animals high in the scale of development. All visible motion is produced solely by the action of muscles. The complicated movements of the higher forms of animal life require a great number of muscles, properly disposed and adjusted in their arrangement, quickly responsive in their action, and nicely-poised, coördinated, and antagonised, in their effect. In man there are, subject to the control of his will, over one thousand muscles, whose mass constitutes half the bulk or volume of the body.

Besides these so-called voluntary muscles, this tissue in the form of fibres or layers enters into the composition of nearly all the organs of the body connected with the vegetative life. The digestive, respiratory, circulatory, genito-urinary, etc., systems are in part constructed of muscular tissue whose insensible action is involuntary, that is, beyond the control of the will.

Striped and Smooth Muscle.

The voluntary are readily distinguished from the involuntary muscles under the microscope by the fact that the voluntary muscle fibres are striped while the involuntary are smooth. Yet there are some exceptions to this rule. The muscle-substance of the heart, for instance, is striped, though its action is entirely beyond the control of the will, as is also that of the pharynx, of the rectum and urethra.

Wherever promptitude of response and power of contraction is needed the muscular tissue is always striped, whether voluntary or not.

In man and the higher vertebrates these two varieties of muscular tissue are distinctly separated, but in the lower vertebrates, and still more markedly in invertebrates, transition forms occur. In the echinodermata (star-fish, sea-urchins, etc.), all the fibres are smooth, as also, in the rule, in the molluscs. In the helminths the muscular fibres are almost always smooth, the only instance of striped muscle existing, strange to say, not in the apparatus of locomotion, but in the uterus of the echinorhynbhus nodulosus (Leydig). It should be stated also in this connection that some fibres which were formerly regarded as smooth are now known to be striped. Thus Margo discovered that the closing muscle of the bivalves, hitherto described as unstriped, under high magnification and fine definition, distinctly exhibits very fine striæ or stripes. And that the marked degree of difference formerly attached to the histological division of muscular tissue no longer holds good is evidenced by the fact, reported by Vierordt, that the same organ in different animals has sometimes striped and sometimes smooth fibres to accomplish the same purpose. In the body of man, the heart, whose action is involuntary, is composed of striped muscle, while the accommodation of vision for objects at different distances, a voluntary act, is effected by the unstriped, involuntary, choroid muscle.

The Color of Muscle.

The deep red color of striped muscle, is partly due to the blood which circulates throughout its substance, in a rectangular network of capillaries, whose distribution is among the finest in the body. The cruel custom prevailed among butchers, formerly more extensively than now, of subjecting young animals, calves, etc., to frequent bleedings before final slaughter in order to render the flesh more tender. The butchers were said to "bleed the animal white" as the muscle thus became much paler in hue, but no abstraction of blood will make muscle absolutely colorless. Even though a muscle be washed free of blood outside of the body, or water be injected into its vessels until it escapes colorless, the muscle substance will still preserve a distinct amber hue, which may be regarded as the intrinsic color of muscle protoplasm. Kölliker observes that the color of muscle is due to the presence of a coloring matter analogous to, but independent of that of the blood, and Fremy has given to this peculiar yellow coloring matter, in the case of the salmon and other fish, the name, salmonic acid. Kühne and Ranvier washed out red muscles with "artificial serum" (a half per cent. solution of common salt) and established the fact that the color of muscle is not due to the presence of blood, but to hæmoglobin.

The Anatomy of Voluntary Muscle.

Striated muscles, of the size and shape adapted for the special purpose, consist of bundles, fasciculi, aggregated in mass, and enveloped in firm but elastic sheets of connective tissue, which also sends in partitions to surround the smaller bundles within. These smaller bundles, with intervening bloodvessels, connective tissue, and fat masses, are distinctly visible on cross section of a muscular mass. In longitudinal separation of the bundles, we finally arrive at the ultimate muscular fibre, with its investing sheet of connective and elastic tissue, the sarcolemma.

The Sarcolemma

forms both the dura and pia mater of the muscular fibre in that by its density it contains the diffluent muscle protoplasm and restrains it from undue dissemination, by its surface it gives space for the rich network of vessels to convey the blood needed in such abundance for muscle work; then by its elasticity it greatly economises muscular force. The transparent, homogeneous, closely adherent, sarcolemma or primitive sheath is readily exhibited by forcibly breaking the fibre in two, continuity being still maintained by the firm, though delicate sheath. On long maceration in water the sarcolemma is raised in blisters (blebs) upon the surface of the fibre.

The Muscle Fibre.

The muscle fibre itself is one of the most complex structures in the animal economy. By long maceration in water or alcohol, or more especially in solutions of the bichromate of potash, it splits up into 3–500 finer fibrillæ running parallel with each other throughout the length of the fibre. By maceration in very dilute hydrochloric acid or in gastric juice it separates into transverse disks with complete obliteration of the longitudinal markings of the fibrillæ. It is a question still unsettled as to which of all these structures, the fiber, the fibrilla or the disk is the ultimate anatomical element. If the muscle tissue be separated in both directions, transversely and longitudinally, it is divided into minute rectangular prisms or caskets, and in sections of frozen muscle the outlines of these prisms are made apparent with their intervening cementing substance. Bruecke has quite recently discovered that the sarcous elements themselves are not elementary and simply solid bodies, but groups of smaller doubly refractile bodies which he calls "disdiaclasts" after the phrase employed by Bartholin, the discoverer of double refraction in calc spar. Immersion in water obliterates all traces of the sarcous elements and dissipates the appearance of striation in the muscular fibre.

In the present unsettled state of opinions upon the subject, we shall continue to regard the muscular fibre, with its enveloping, nucleated, sarcolemma, receiving the last distribution of the vessels and nerves, as the ultimate, anatomical, element of striped muscular tissue. The fibre is the cell and the sarcolemma is its wall. Krause has repeatedly teased out muscle fibre under various reagents and found it never more than 4 ctm. (1.6 inch) in length.

Muscle Protoplasm.

The proper protoplasm of muscle, in its living state, is soft, even semi-fluid. For some time after removal from the body the fresh surface of a mass of muscle in the butcher's stalls trembles or palpitates under a current of air. The diffluence of muscle is seen to advantage in the wave-like flow of its protoplasm towards the negative pole on the application of electricity. So long as it is not excited, it follows gravity in all directions. Kühne has seen a filaria swimming about among, and winding in between, individual sarcous elements without injuring or displacing them, the muscle protoplasm closing in behind it, without leaving any line or trace of its track.

The muscle fibres collected into primary bundles, fasciculi, and these again into larger, secondary and tertiary bundles finally constitute, *en masse*, as we have seen, the individual muscle.

General Properties of Muscle.

The muscles vary greatly in their shape, in their bulk and in their weight. The vastus externus and the glutei are masses of muscular substance weighing pounds; the small muscles of the middle ear weigh but a few grains. There is full as great variety in their shape. Muscles are long at the extremities, broad and flat in the trunk, short and thick about the head and neck. The more fixed point of origin is called the head or origin of the muscle, the more movable point of insertion, the tail or insertion, the expanded intervening portion is the body, the venter or the belly.

Names of Muscles.

Hence are the names gastrocnemius, digastricus, biceps, triceps, etc., bellied, double bellied, two and three headed muscles, etc.

Muscles are also named according to their uses, as diaphragm, buccinator, extensors, flexors, adductors, abductors, levators, depressors, tensors, dilators, etc.; or, according to their positions, as interspinales, interossei, subclavius, popliteus, temporalis, occipito-frontalis, etc.; or, according to their shape, as trapezius, splenius, lumbricales, scalenus, deltoid, gracilis, etc.; according to their dimensions, as pectoralis major and minor, gluteus maximus, medius and minimus; according to their composition, as semi-membranosus, semi-tendinosus, complexus, etc.; according to their attachments, as sterno-cleido-mastoideus, genio-hyo-glossus, etc.. The gemelli form a pair of twins, the sartorius crosses the legs for the sartorial (tailor's) posture, and the risorius produces a smile. "He who rejects with scorn," said Mr. Darwin, "the belief that the shape of his own canines and their occasional great development in other men, are due to our early progenitors having been provided with these formidable weapons will probably reveal by sneering the line of his descent. For, though he no longer intends, nor has the power, to use these teeth as weapons, he will unconsciously retract his 'snarling muscles,' so named by Sir Chas. Bell, so as to expose them ready for action, like a dog prepared to fight."

Form and Shape of Muscles.

Muscles are said to be simple, when all the fibres are similar in direction in a single body, as in the sartorius; they are compound, with one body and several heads or tails, as the flexors of the fingers and toes; radiated, when spread out like a fan or a wheel, as the temporal and the diaphragm; pennated, when arranged like the feathers upon a quill, as in the palmaris longus; hollow, as in the heart, the uterus and the bladder (Dunglison).

Most curiously arranged, finally, are those double bellied muscles, which are caught at the middle by an attachment, sometimes as by a pulley, and thrown off to exercise their force in a different line from that assumed at their origin, as the digastricus, and the superior oblique muscles of the eyes.

These are mostly anatomical points, it is true, but are mentioned here for the sake of exhibiting the individuality of muscles.

Smooth Muscle.

The construction and disposition of the smooth involuntary muscle fibre is much more simple. It presents itself in the form of elongated, spindle-shaped cells, whose ends appear drawn out to lines of extreme tenuity, and whose central nucleus, rendered more apparent under the action of a strong acid, is a long cylindrical rod with blunt or rounded ends. Sometimes the cell is so much reduced apparently, by elongation, as to resemble the threads of filiform connective tissue. This is the case in the intestine, ureters and bladder. On the other hand, in the trunk of the aorta, the smooth muscle cell is so short, thick, and irregular, as to be with difficulty distinguished from epithelial cells. It is only by following out the vessel into its branches, where the cells begin to elongate, and observing the transition forms, that the distinction can be made. These shorter, thicker, cells would seem to be a persistence of the embryonic stage, for at the period of original development all the involuntary muscle cells present this appearance. I may state here, parenthetically, that, according to Lockhardt Clarke, muscular fibre can be first distinguished in man, about the fourth or fifth week of utero-gestation.

Disposition of Smooth Muscle.

Smooth cells, arranged side by side, dovetailing, at their ends, with other cells, form the layers, thin and single, or thick and multiple, by superimposition, which constitute an essential feature in the walls of the various vessels, tubes, bladders, etc., connected with the vegetative apparatus of the body. Thus, they form the chief coat of the middle sized arteries, two extensive layers (the submucous and subperitoneal) of the intestine, an important constituent in the walls of the bronchial tubes, extending down to and between the pulmonary alveolæ, the middle coat of the gall and urinary bladders, renal pelvis, ureters, and urethra. They occur in the skin, in the form of small rods or bundles (arrectores pili) attached to the hair bulbs, and connected with the oil and sweat glands, or in the form of a more continuous layer, as in the tunica dartos of the scrotum. In the male organs of generation, smooth fibre is met with in the ducts in, and leading out from the testicle, in the large so-called glands (Cowpers and the prostate) at the root of the penis, and forms an important ingredient in the construction of the penis itself. In the female organs of generation, it is found in the ovaries, the round and broad ligaments, forms a coat in the walls of the Fallopian tubes, and constitutes the bulk of the uterus, which is the largest mass of it in the body. Thin layers and fine bundles of smooth muscular fibre are also found in the mucous membranes (as in the digestive tract), in the interior of solid organs (as in the calyces of the kidney and in the spleen). Finally, of this tissue are formed the involuntary muscles of the eye, the contractors and dilators of the pupil, and the (ciliary) muscle of accommodation. In short, all visible contractility, independent of the striped fibres, is due to the presence in the organ or structure of this smooth, white and involuntary muscular tissue.

The Chemistry of Muscle.

However much the two kinds of muscular tissue may differ in appearance or in action, their chemical composition is precisely the same. Three-fourths of the substance of muscle is water. Of the remaining fourth, one-half is the coagulable albumenoid principle peculiar to muscle, known as myosin. Myosin may be separated from living muscle by freezing it, mincing it, and rubbing it up in a mortar with four times its weight of snow, containing one per cent. of common salt (Kühne). The resulting mixture, the muscle plasma, as it is called, soon gelatinises to a firm mass, which afterwards separates into a clot and surrounding fluid. The clot is myosin; the fluid, muscle serum. As the products of metamorphosis, there are found in muscle numerous extractive matters, as creatine, xanthin, hypoxanthin, sarcosin, inosite, and traces of uric acid, though "urea is conspicuous by its absence." Nearly 80 per cent. of the ash of muscle is composed of the salts of potash and phosphorus.

The Reaction of Muscle.

The reaction of fresh muscle, at rest, is neutral or faintly alkaline, but during and after contraction it is acid. The peculiar form of lactic acid found in muscle is directly generated by the oxidation of the carbo-hydrates of the blood, and when small in quantity, as during rest of the muscle, is neutralised by the alkalinity of the blood; but when its quantity is much increased, as during the rapid oxidation attending contraction, it cannot be sufficiently neutralized at once, and accumulates to render the muscle acid for a time. So the free access of oxygen soon renders acid a freshly dissected muscle, separated from the body. The accumulation of acid in the muscle marks the stage of weariness or fatigue. Ranke found that a frog's muscle which had become powerless from fatigue was speedily restored to activity after the injection (from the heart) of very weak solutions of carbonate of soda, which carried off the acid by presenting it a base. Fresh and active muscle is speedily rendered powerless by the injection into its vessels of even highly diluted lactic acid.

Specific Properties of Muscle.

The muscular is said to be one of the master tissues of the body, and whether we regard the nature or the mere number of the properties with which it is endowed, there appears to be justification for assigning it to this dominant place. For muscle has the passive property of elasticity; that kind of constant, effortless, insensible, contraction known as tonicity; a peculiar sensibility; and, higher than all these, a characteristic contractility, which makes itself manifest in, and is, in part, the immediate cause of nearly all the phenomena of animal life. In addition to all these properties, muscle generates heat and electricity, and in its action produces sound, which is, however, an effect rather than property.

The Elasticity of Muscle.

Elasticity is a property possessed by muscular tissue in high degree. The semi-fluid muscle protoplasm, is itself somewhat elastic or resilient, and the sarcolemma, the investing sheet of connective tissue, is highly elastic. It is the extensibility and elasticity of muscles at rest which permit the bones to be moved in different directions by antagonistic muscles, and it is to the property of elasticity alone, or in great part, that is due the restoration of, so to speak, displaced members to their former place. The purely passive property of elasticity thus greatly economises active muscular force. It is always ready, requires no innervation, and manifests its action at once. It permits the walls of hollow organs, like the stomach, the bladder, and the uterus, to be more or less distended, reacting all the time upon their contents, to assist the active property of muscle in securing their extrusion. The auricles of the heart, for instance, are passively distended or dilated with the ease of a soap bubble, by the influx of blood, and are emptied almost entirely without the intervention of active muscular force. The degree of elasticity is different, of course, in different muscles, being dependent upon the size of the muscle and the quantity of accessory structure (connective and elastic tissue) it may contain. But the elasticity of muscle far surpasses that of most other elastic bodies. A bundle of silk threads or of metal wires will not suffer the same extension without rupture. Muscle resembles more closely a bundle of threads of caoutchouc or India rubber.

The specific elasticity of a substance is determined by the weight or force required to extend it within the limits of perfect restoration. If we compare, thus, different substances with muscle, it is found that the weight required to extend the one-thousandth of its length, a rod or thread of one square millimeter diameter would be as follows:

	Grammes.	Grains.
Steel,	17278000	(1151866)
Copper,	10519000	(701266)
Pine wood,	1113000	(74200)
Frog's Muscle,	273	(18)

These figures represent the co-efficient of elasticity of the different substances.

Of course, there are limits to the elasticity of muscle. Thus Marey found that the detached gastrocnemius muscle of the frog could be extended with a weight of 300 grains to the degree of the one-fiftieth of an inch with perfect recovery after removal of the weight, while a weight of 750 grains completely disabled its elasticity. Moreover, rapidly repeated subjection to experimentation diminishes and finally exhausts the elasticity of muscle, inducing the relaxed and flabby state, characteristic of fatigue.

Tonicity of Muscle.

Tonicity has been described as insensible contraction of muscle, inherent in the muscle protoplasm itself, and independent of the nervous system. It was said to manifest itself in the retraction of muscle cut across (gaping of wounds), and in the distortion of the paralysed side of the face in facial hemiplegia from traction by the sound side. But recent experiments have clearly demonstrated that both these phenomena are due to elasticity. The muscles are always somewhat stretched beyond their normal length, so that retraction of divided surfaces is a natural result of section. Both time and force are thus economised by this elongation and elasticity of muscular fibre. Muscles stretched by the contraction of opposing muscles fairly spring back to their former position without effort or loss of time. When a muscle is separated from its attachments it shrinks upon itself, and the muscular tubes (fibres) are seen, under the microscope, not to lie in straight, but in wavy or zig-zag lines. It is the advantage taken by the persisting elasticity upon the sound side, of the impaired elasticity on the affected side, that produces the distortion of the face in facial palsy.

Nevertheless, there is an insensible and involuntary contraction (tonicity) of all the muscles, both voluntary and involuntary, which manifests itself in the muscles of the skeleton as well as in the smooth fibre, where it secures a certain tonicity of the vessel walls, of the sphincters, etc.

Tonicity, a Reflex Phenomenon.

But this tonicity is by no means an independent property in the muscular tissue. It is derived entirely from the nervous system, and is a purely reflex phenomenon. Up to even a short time ago, this influence of the nervous system upon the muscles, was regarded as an automatic, an original or spontaneous action, developed in the spinal cord. It is now known, however, that this action is excited by outside (peripheral) influences, and is conducted through sensitive nerves (from the skin, etc.) to the cord, whence it is transferred through motor nerves to the muscles. For it has been shown by Brondgeest that section of the sciatic plexus of nerves on one side in the frog, after division of the spinal cord below the medulla oblongata, destroys the tonicity of the muscles upon the operated side, while it is left intact upon the sound side. When a frog thus operated upon is suspended, all the joints upon the operated side hang loose and flabby, while those on the sound side still retain their natural degree of flexion. Liègeois cut the sciatic nerve in the frog upon one side only, and then divided the gastrocnemius muscle upon both sides, when it was observed that the retraction (gaping) was much less marked upon the operated side.

That this influence from the nervous system is entirely reflex is proven by the fact that section of the posterior (sensitive) roots of the nerves has the same effect as section of the entire nerves. Moreover, after section of the posterior nerve roots, a stronger irritant must be applied to the anterior roots to produce the same convulsive movement in the muscles, proof that additional artificial, is required to substitute the lacking natural, stimulus.

Tonicity of Involuntary Muscle.

A continuous, though feeble, discharge of nerve force is also received by the involuntary muscles securing to them a constant tonicity. After section of the nerves distributed to their walls, the vessels dilate, and that this influence also comes from the cord is proven by the observation that spinal hemiplegias are attended with paralysis of the arteries only upon one side. Here again, however, we have to deal with reflex and not automatic processes, for Goltz has demonstrated that vessel tonicity may be affected (increased) by irritation of distant sensitive nerves or surfaces, as from the intestines, or paralysed by their destruction. So strychnia will continue to cause contraction of arteries below the line of section of the spinal cord.

The sphincters are held in a state of continuous contraction in the same way. Giannuzi and Nawrocki found that more force had to be used to overcome sphincteric contraction (by the injection of water) when the nerves were intact than after their division. Heidenham and Colberg had already demonstrated this fact with regard to the bladder. They introduced water of the temperature of the body into the interior of the bladder of a rabbit, and observed, by means of a manometer, that it required a pressure of 27 centimetres to overcome the tonicity of the sphincter and permit escape of the water. They now killed the animal to annul all innervation, and found that the water escaped at a pressure of 5 centimetres. In the dog a higher pressure was required in both cases, but the result was the same. It is probable that the remote exciting agencies producing the tonicity of the sphincters, the bladder, the dilator pupillæ, etc., are the nutritive changes in constant operation about the peripheral distribution of the nerves, as well as in the nerve centres themselves.

The tonus of muscle, therefore, is no proof of the spontaneous generation or automatism of force. Closer investigation always dissipates such conceptions and it is probable that this term will in a few years be entirely discarded from physiology, will be shelved away along with other "vital forces," with the autochthonous (spontaneous) or idiopathic genesis of disease, and other mysteries of medicine.

The Sensibility of Muscle.

Sensibility is that peculiar property which enables us to estimate the amount of effort necessary to execute different movements, to overcome resistance or to appreciate different weights. It is some times described as a sixth special sense, oftener as a general sense, and occasionally as a kind of transition sense between the two. Those who deny its independent existence regard it as a peculiar modification of the sense of touch. In fact three theories have been propounded to account for the muscular sense: 1, that there are no special sensitive nerve fibres distributed to muscles. We are cognisant only in a general way of the amount of nerve force sent to a muscle though its motor nerves. We recognise the intention of muscular movement but not its execution (Wundt): 2, We are informed of the contraction of muscle only by the sensations produced in the skin or mucous membrane covering them, that is, through the tactile sense (Auber); 3, Centripetal (sensitive) nerve fibres pass from the muscles to the nerve centres (Arnold, Brown-Séquard, etc.).

Sensibility and Sensation of Touch.

That the muscular, is entirely independent of the tactile, sense, was demonstrated some time ago by Claude Bernard who found that removal of the skin (decortication) did not at all affect the sensibility of the subjacent muscles. Complete insensitiveness of the skin was also produced by division of all the cutaneous nerves, but the muscular sense still remained intact, as the animal thus operated upon continued to be able to walk, etc. If, however, the posterior (sensitive) nerve roots were cut, the muscular sense was very greatly impaired or entirely destroyed. Moreover, the muscular sense is much finer than the tactile sense; it will appreciate lighter shades of difference. The feelings of weariness or fatigue which supervene after violent or long continued exercise, the positive pain experienced in the cramp of tetanus, the spasm of convulsion, or even the exaggerated physiological action of the uterus (labor), or heart (palpitation), are pathological and physiological proofs of a muscular sense dependent upon the existence of sensitive nerves. In truth, C. Sachs found, after division of all the anterior (motor) nerve roots, some undegenerated nerve fibres in the sartorius muscle of the frog which could, of course, belong only to the posterior (sensitive) roots. Terminations of sensitive nerve fibres, corpuscles of Pacini, had long before been discovered in quantity in the perimysium, and about the joints, at the points of insertion of the tendons, whose function in all probability is to receive and transmit the muscular sense. Lastly, the tactile sense may be entirely paralysed, while the muscular sense remains intact, or vice versa. Thus in locomotor ataxia, the tactile sense may be little or not at all affected, while the muscular sense is so much impaired as to require the aid of visual sense in walking. "We lean upon our eye-sight in walking," said Mr. Mayo, "as upon crutches." An individual thus affected falls when he closes his eyes. Duchenne has put upon record the curious case of a nurse, who had lost the muscular sense in one of her arms, and who could only carry a child by constantly watch-ing that arm; as soon as she turned her eyes away from it, the limb would fall helpless to her side. But in this case the cutaneous sense was not affected. On the other hand, there are certain diseases of the spinal cord in which the sense of touch or pressure in the skin is entirely annulled, while it persists intact in the subjacent muscles. Thus, the case is reported by Eigenbrodt of a patient who could distinguish, by the effort of lifting, the difference between thirty and thirty-two pounds, but could not feel a five pound weight resting upon his passive hand.

Of the ordinary sense of touch, muscle possesses little or none. The pain experienced in amputations, belongs to the section of the skin, and is scarcely perceived in the division of the muscle or bone. Muscle may be cut, pinched, burned, subjected to all kinds of irritation, without exciting much, if any, pain. It is believed that even the intense pains of cramps are due simply to the violent traction upon the points of origin and insertion of the muscle. The involuntary muscles are equally devoid of the sense of touch or pain. Haller could never excite pain in his experiments upon the heart, and Harvey found that he could manipulate it freely in a case of its exposure after caries of the sternum without producing the least sensation. Bichat made the same observation upon the bladder, and every gynæcologist is aware of the insensibility of the uterus, whose cervix is burned, scraped and even split, almost without consciousness on the part of the patient.

The Sensation of Fatigue.

But the muscles are extremely sensitive to the peculiar pain of muscular fatigue, which continues to be felt long after its cause has been relieved. Weber has shown that the fatigue of muscle is due to chemical change in the muscle substance, to the consumption of oxygen (Pettenkofer and Voit) and to the accumulation of the products of oxidation (carbonic acid, lactic acid, acid phosphate of lime, etc.—Ranke). We can thus understand how it was that Bichat could produce violent pain in muscle by injecting into the arteries of living animals irritating fluids, like ink, dilute acids, and wine. The fatigue of muscle must continue until the blood shall have had time to decompose or conduct away the irritating matter. Hence, the efficacy of hot baths and massage (friction), which by accelerating the capillary circulation, more quickly dissipates the products of muscular action (products of combustion).

The rapid accumulation of these products of decomposition in fever, which is, in essence, a too rapid oxidation, accounts for the deep seated muscular pains (as in "break bone fever," lumbago of the exanthemata (small pox), etc.) attending this condition.

The Exercise of the Muscular Sense.

The muscular sense is thus quite distinct from every other sense. It acquaints us unconsciously with the position and relations to each other of the various parts of the body and informs us of the position and properties of external bodies. It enables us to appreciate differences beyond the range of other senses. Thus it is finer than the sense of touch. It will correctly discriminate between weights which stand to each other in the relation of thirty-nine and forty, provided the weights are not too light or too heavy (Weber). Increase is easier detected than decrease (Panum and Dohrn). It estimates with the finest nicety the degree of contraction to be excited in a muscle, or group of muscles, for the execution of a given purpose, and makes us cognisant of the exact degree of contraction and relaxation existing during the execution of the movement. The muscular sense thus establishes the harmonious and coördinate action of the different muscles in all the voluntary and involuntary acts of the body, in assuming and maintaining its different positions, as in standing, walking, balancing, dancing, riding, swimming, etc.; in executing the finer movements of the handicrafts, playing upon musical instruments, etc.; in arranging the features and changing the expression of the face and members in the infinite variety of gesticulation; in the quick movements of the eye, and, finest and nicest of all, in the delicate modulations of voice and speech.

So it was no wonder that Sir Chas. Bell, the eloquent English anatomist, could not restrain himself after observing the fineness and nicety of the action of the muscular sense, from expressing his admiration in a fitting tribute of praise. "When," he exclaims, "a blind man or a man blindfolded, stands upright, neither leaning upon or touching aught, by what means does he maintain his erect position? The symmetry of his body is not the cause. A statue of the finest proportion must be soldered to its pedestal, or the wind will cast it down. How is it, then, that a man sustains the perpendicular posture or inclines in the due degree towards the wind that blows upon him? It is obvious that he has a sense by which he knows the inclination of his body; and that he has a ready aptitude to adjust the parts of it so as to correct any deviation from the perpendicular. What sense is this? He touches nothing, sees nothing; it can only be by the adjustment of the muscles that the limbs are stiffened, the body firmly balanced and kept erect. In truth, we stand by so fine an exercise of this power, and the muscles, from habit, are directed with so much precision and with an effort so slight, that we do not know how we stand."

Such is what is meant by the muscular sense. The Germans, very appropriately call it the "*Gemein-gefühl,*" the general or common feeling of the body. The vigor of this sense is a criterion of health; it was the *euphora* of the ancients, the easy carriage and light weight of the body. The muscular sense is the physical conscience. The individual who has this conscience or consciousness sound, enjoys a luxury in mere existence.

LECTURE X.

MUSCLE AND ITS PROPERTIES.

CONTENTS.

Contractility of Muscle—Effects of Muscular Contraction—Degree of Contraction—Change of Form—Agents which Induce Contraction—Direct and Indirect Excitation—Thermal Excitation—Electric Excitation—The History of Galvanism—The Action of Induced Electricity—The Action of Nerve Force—The Sound of Muscle Contraction—The Muscular Wave—Independence of Muscular Force—The Action of the Sulphocyanide of Potassium and Curare—The Generation of Heat—The Generation of Electricity—Du Bois-Reymond's Theory of Muscular Action—Rigor Mortis—Post-Mortem Changes in Muscle—The Fuel of Muscle—The Oxygen Supply—The Dependence of Muscle upon Blood—The Muscles as Levers—The Absolute Power of Muscle—The Power of Muscle in General—Differences of the Sexes—Differences in Different Animals—The Velocity and Delicacy of Muscular Action.

We have to-day to conclude the study of muscle with the consideration of its remaining properties, the chief of which is

Contractility.

We observe then, first, that the mode of contraction is very different in the two kinds of muscular tissue. Striated muscle responds to an irritant almost suddenly, always forcibly, and as quickly returns to its former state. Smooth muscle responds slowly, always comparatively feebly, and as slowly returns to its former state. The slow, undulatory, so-called peristaltic, action of the smooth muscle of the intestinal walls, manifest upon laying open the abdominal cavity of an animal, best exhibits the mode of contraction of smooth muscle fibre. The intestines, at first motionless, soon exhibit feeble contraction, which gradually increases to vermicular motion, until the whole canal "writhes like a mass of earth worms," to gradually become again quiescent. The uterus in labor typically exemplifies the action of involuntary muscle. If the hand be placed upon the abdomen at the commencement of a pain, the uterus is felt to "gather up" its fibres, to become gradually indurated, and then slowly to relax to the condition in the intervals between pains. The character of the pain itself, a gradual increment to an acme, and then a gradual decrement to more or less complete relief, exhibits the absence of any sudden force.

But there is a difference in the quickness or sluggishness of response in different involuntary muscles. Thus the muscles within the eyeball, *i. e.*, the muscles of the iris and the tensors of the choroid (muscles of accommodation), respond very nearly as promptly as voluntary muscles; next in order of promptness rank the muscular walls of the intestines and ureters, and slowest of all, is that of the bloodvessels, especially of the arteries, which, however, compensate for it in some degree by the long persistence of contraction.

Legros and Onimus concluded from their observations, that smooth muscle was influenced more by direct excitation of its substance than by excitation of the nerves, and that the disuse, which would reduce striped muscle to an inactive mass of fat, had little or no effect upon the anatomical or physiological integrity of smooth muscle.

The voluntary muscle fibres reach the bones only by the intervention of membranes and tendons. Each fibre is reduced at its end to a point, with flat, facetted, sides, like a diamond or a sharpened lead-pencil, and is thus embraced by the connective tissue structure of the tendon. The tendon is the conductor of force. It plays the part of the line which connects the horse to the canal-boat.

Effect of Muscular Contraction.

Shortening is only another name for contraction. In contracting, muscle shortens, and, in the case of long muscles, approximates the connected bones. Muscles in the form of tubes (canals, vessels, etc.) diminish, in shortening, the caliber of the tube or obliterate it altogether. It is the spasmodic contraction of the cerebral vessels, which induces the profound anæmia of the brain and pallor of the face as the immediate cause of epilepsy. And it is this exercise of contractility in lesser degree which regulates the blood supply to individual organs independently of the action of the heart. The bloodvessels become, thus, local hearts, at the portals, and in the substance, of each organ and structure to increase or diminish the supply of blood according to the demand. Something of this local increase and decrease is observable in the face under the action of the emotions. The face is suffused with blood under the excitement of modesty or shame and is blanched under anxiety or fear. Thus, Donne says:—

> "The eloquent blood
> Spoke in her cheeks, and so distinctly wrought,
> You might have almost said her body thought."

And Petrarch descants upon

> "Quel vago impallidir."
> (That charming pallor.)

A vaulted muscle has its arch reduced by contraction, brought nearer to a plane surface, and thus, in the case of the diaphragm, is the vertical capacity of the chest increased and inspiration effected. Ring muscles, like the sphincters and orbiculars, in contracting, "purse up" their respective orifices, and hollow muscles obliterate their cavities to entirely empty themselves of contents.

Degree of Contraction.

But it is only in extreme cases of cramp, as in tetanus, or in extraordinary effort, that a muscle attains its utmost degree of contraction. The bones very greatly limit the contraction of the long muscles. Thus the biceps will contract, when detached, nearly five-sixths of its length, but, attached, its shortening is limited to but one to two-sixths. In tetanus it may reach three-fifths. Strange to say, it is no matter how much muscles vary in size or bulk, the per cent. shortening remains about the same. Some muscles (the glutei) weigh pounds, or measure feet in length (the sartorii), and others, the muscles of the middle ear, but a few grains, and measure but a few lines, but the proportionate shortening remains about the same.

Change of Form.

The loss which a contracted muscle has experienced in length is in very nearly exact correspondence to its gain in breadth. We may feel the muscles (biceps) in action swell. It was formerly believed that muscle absolutely gained in bulk, but the ingenious experiments of the older physiologists entirely disproved this belief. Thus Sir Gilbert Blane inserted a glass tube into the perforated cork of a glass jar and filled the jar with water up to a certain level in the tube. He now introduced a living eel into the jar and irritated it by means of a stick, also inserted through the cork, to active contractions. Though the slightest increase in the bulk of the animal would have been registered in the tube by an elevation in the column of water, no such change in its level could be observed. Barzellotti made the same experiment with a frog, inducing contractions in the half of its body, which had been introduced into the jar, by means of galvanism, with the same result. The truth is, muscle rather diminishes than increases in bulk during contraction. Erman was able to make this observation by repeating the experiment of Blaine and taking the precaution to graduate the glass tube to great nicety. Valentin appended a weight to a marmot's muscle, suspended in a jar filled with dilute albumen, so that its specific gravity could be accurately weighed upon delicate scales, and observed that the muscle in contracting, displaced less water than before. He thus found that while the specific gravity of the muscle increased from 1061 to 1062, its loss in volume amounted to $\frac{1}{1370}$ of its whole mass, a diminution so slight as to be generally unconsidered. Practically, a muscle gains in thickness what it loses in length. If a lever be laid upon a muscle placed horizontally, "the thickening of the muscle will raise up the lever, and cause it to describe on a recording surface a curve exactly like that described by a lever attached to the end of the muscle" (Foster).

Agents which Induce Contrction.

The agents which may induce contraction in muscle are very various. Any mechanical force (a blow, a prick), any chemical irritant (cholic acid), sudden change of temperature, the various forms of electricity, may evoke fibrillar twitchings or mass motion. But in the body, muscle contracts only in obedience to nervous influence. In other words, muscle tissue is something like the machinery of an engine. It has the capacity for work, but can not work of itself; it must first be stimulated by extraneous forces, that is, muscle is machinery for the transformation of some other force into muscular force.

Direct and Indirect Excitation.

The outside force may act upon the muscle directly, or it may act upon the muscle through the intervention of the nerves. As a rule, the agents which superinduce direct muscular contraction will also effect it indirectly. Kühne, who has made an exhaustive study of this subject, states that there are some substances which easily cause contraction of muscles when applied to them, even if greatly diluted; whereas, to produce the same effect through the nerves, they require to be concentrated. Among these, are the mineral acids, especially muriatic and nitric acids; the basic salts, as chloride of sodium, chloride of potassium, chloride of lime; as well as some organic substances, as acetic acid, lactic acid and glycerine. A second class of substances induce contraction equally whether applied to the nerve or to the muscle. Among these are caustic potash or soda. A third class of chemical substances act powerfully on the muscle, but not at all upon the nerve; such as chromic acid, sulphate of copper, chloride of iron, basic and neutral acetate of lead, lime and, above all, ammonia. A fourth class of substances act exactly in an opposite manner, that is, upon the nerve, but not on the muscle, or very slightly so; such as creosote, alcohol, concentrated glycerine and undiluted lactic acid. Finally, a fifth class exists, which have no power of producing contraction when applied to either muscle or nerve; such as the fatty oils and turpentine (Bennet).

Thermal Excitation.

Different muscles also react differently to the same irritant. This is notably the case in regard to the effects of heat. A moderate degree of heat, 35° C. (95° F.), increases, while cold diminishes the contractility of muscle. Everyone is familiar with the sluggishness of muscular action under extreme cold. But an extreme heat absolutely destroys muscular power and destroys muscle by coagulating its myosin. Though myosin coagulates at a much lower temperature than any other albumenoid substance, the degree of temperature at which such molecular change occurs varies in different species of animals. Thus myosin coagulates in the frog at a temperature of 34° C. (93° F.), in mammals at 45° C. (113° F.), and in birds at 48° C. (118½° F.). Subjected to a temperature of the freezing point of water, muscle soon loses its irritability, but not beyond the power of perfect restoration. But if muscle be kept at a temperature much below this degree, its irritability is soon permanently destroyed.

Sudden changes of temperature, short of these extremes, affect different muscles differently. Weber and Calliburces long ago noticed the fact, which is now the subject of daily observation in physiological demonstration, that the heart's action when flagging with exhaustion is very decidedly stimulated by the application of heat, and Milne Edwards has remarked upon the increased contractility of most of the smooth fibres, the dartos, the uterus, and the intestines under the application of heat. The muscles which are thus excited to contraction are said to be thermosystaltic, while the muscles of animal life are athermosystaltic. In the fœtus, which has the circulation of a cold-blooded animal, all the muscles are thermosystaltic. Hence the efficacy of the application of heat in cases of still birth.

Electric Excitation.

But of all irritants or stimulants of muscular contractility, none so nearly resembles the natural stimulus of nerve force as electricity.

The first recognition of the action upon muscles of the electric spark was made about the middle of the seventeenth century, but it was not until a century later, September 20, 1781, that Galvani, Professor of Anatomy and Physiology at the University of Bologna, made the brilliant observations that have immortalised his name in that of the form of electricity which he employed.

The History of Galvanism.

The history of the discovery of galvanism is worthy of note, as showing how the simplest observations lead, in a reflecting mind, to the most important results. The story runs that Madame Galvani was preparing some recently decapitated frogs for the dining table, when she observed that the apparently dead animals became convulsed when brought into the neighborhood of an electrical machine in action. Prof. Galvani next remarked that the convulsions only ensued when a spark was emitted from the machine, and when, also, some metal substance came in contact with the exposed nerves of the frog. With a view of discovering whether atmospheric electricity would exercise the same effect, he suspended the frogs from the iron trellis work surrounding the roof of his house by means of copper hooks "and saw, when they were blown about by the wind, that convulsions were caused whenever they came in contact with the iron." Galvani, however, made the mistake of believing that the electricity thus engendered was inherent in the muscle and was the source of all vital action, an error which led to the famous altercation with Volta, extending over a series of years, conducted on both sides with much acumen and too much acrimony, and finally eventuating (but after Galvani's death), as usual in such cases, in proof that each was right and each was wrong. "Galvani was right in maintaining the existence of an animal electricity, but was wrong in believing it proven by the contact of two metals; Volta was right in maintaining that galvanism could be produced independently of animal bodies, but was wrong in denying the existence of animal electricity."

The immediate response of living muscle to the action of electricity renders it a galvanometer of exquisite sensitiveness. A frog prepared for experimentation by decortication and exposure of the lumbar nerves, is known as the rheometric or galvanoscopic frog.

The Action of Induced Electricity.

When an interrupted current of electricity, of whatever source, static, magnetic, galvanic, is sent through a voluntary muscle, contraction of the muscle immediately supervenes. At least, it is immediate to gross observation. If, however, the periods of time be measured by mathematical instruments of great nicety, or, if the movement of the muscle be represented in exaggerated form, as by the attachment to it of a long, delicate, lever (the myograph), which shall register the tracing of the muscle with great accuracy, it is seen that a short, but appreciable, interval of time lapses between the application of the stimulus and the movement of the lever. This interval is known as the "pose" of the muscle, and occupies about the $\frac{1}{70}$ of a second. Now the lever is rather abruptly raised, and if its point be traversed by a sliding plate, evenly run by clock-work, it traces an obliquely ascending arc, the elevation of which corresponds to the force of the contraction. When the point of the lever has reached its highest point, in a period of time occupying about $\frac{1}{20}$ of a second, the contraction has ceased, whereupon it falls in a descending curved line, occupying in its trace about $\frac{1}{30}$ of a second, to its original level. The curve registered in this way is known as the "muscle curve." Thus the muscle, in its entire contraction, occupies the $\frac{1}{70}+\frac{1}{20}+\frac{1}{30}=\frac{1}{10}$ of a second.

A second shock of electricity, of course, repeats these phenomena in every particular, but if a second shock shall have been entered before entire relaxation has occurred, the muscle curve will not fall to its original level before it is caught again, so to speak, and forced to rise. Now, if repeated shocks be entered rapidly, but not too rapidly, the curve will be held high on the plate, and the rise and fall of each contraction and relaxation will be very slight. At ten shocks (vibrations of the fork) per second, the distinct effects of each still remain visible; at fifteen, the individual shocks begin to become fused, and at twenty vibrations to the second, the muscle is held permanently contracted. This constitutes what is known as tetanus. We use the ordinary Faradic battery as a good instrument for the exhibition of the spasmodic contractions of individual shocks, and the small French Voltaic battery to exhibit the tetanising effects of rapidly succeeding shocks.

The Action of Nerve Force.

The constant current of electricity produces contraction in the muscle only at the moment of making and breaking contact. During the steady, constant, flow of the electric force, the muscle remains perfectly passive and unaffected. When muscle contracts physiologically, that is, under the influence of nerve force, it is held contracted, as in tetanus, until the stimulus from the nerve is voluntarily or involuntarily withdrawn. The inference is, hence, plain, that nerve force is sent to muscle, not in a continuous, but in an interrupted current. And as muscle does not contract spasmodically under nervous force, this force must be transmitted to muscle in a series of vibrations, numbering at least twenty to the second.

The Sound of Muscle Contraction.

What lends to this inference additional support, is the fact that muscle, in contracting, produces sound. Sound implies, of course, a series of vibrations. A body at perfect rest emits no sound. Muscle emits a sound which is distinctly audible. If a stethoscope be placed over a contracting biceps, a humming sound is distinctly perceived, or if, in the stillness of the night, the ears be stopped with the fingers and the jaws firmly closed, the sounds of the powerful flexors of the jaw may be clearly perceived. The note emitted by the sound of contracting muscle is always the same. It indicates twenty vibrations to the second. This is the "music of motion," and

> "Such are the subtle strings in tension found
> Like those of lutes, to just proportion wound
> Which of the air's vibration is the force." Blackmore.

The Muscular Wave.

From what has been already said, it is plain that muscle has no power to contract of itself. In other words, muscle possesses no automatism. It has the capacity for work, but exhibits this capacity only under stimulus. This stimulus is imparted physiologically, as we have seen, only by the nervous system, and is manifested first, as would have been assumed, at the points where the nerve reaches the muscle. As a nerve is about to be distributed to muscle, it subdivides into a leash or into branches, like a whip-lash with many tails, and these branches, containing at their termination in the muscle only the essential conducting element of nerve force, fuse with an accumulation of sarcolemmar nuclei, which are collected to form a disc or plate at certain points on the surface of the muscle fibre. The muscle fibre begins to swell in thickness at this point, and at other similar points, so as to present the appearance of a beaded rod. The beads or swellings, under continuing contraction, continue to increase in size, so that the intervals are absorbed, so to speak, in contiguous enlargements, until the whole fibre and the whole muscle is gathered up into a globar or rather a fusiform mass. By means of ingeniously contrived apparatus, Aeby was able to estimate the velocity of the muscular wave at 40 inches (1 meter) per second, a rate, thus, much more rapid than ordinary protoplasmic (*e. g.*, ciliary) motion, but much less rapid than nerve force. Hence muscular force is not nerve force. Nerve force is the separate force which evokes muscular force.

Independence of Muscular Force.

The independence of muscular force is likewise proven by the fact that muscle removed from all connection with the nervous system will still respond to other stimulus. Still living muscle will continue to contract, under stimulus, when entirely removed from the body, and will continue to respond to artificial excitation in the body after the nerve force has been annulled by section of the nerve fibre and death of its peripheral end. Thus Longet, in 1841, cut the facial nerve and found that it lost its irritability entirely in four days. But the muscles supplied by this nerve continued contractile for more than twelve weeks.

Action of Sulphocyanide of Potassium and Curare.

But the most striking and irrefragable proof of the independence of muscular contractility was established by Claude Bernard in the discovery of the action of an agent, the sulphocyanide of potassium, which paralysed muscular irritability without affecting that of the nerve, and of the action of an agent, woorara, which paralysed nervous irritability without affecting that of the muscle.

The solution of sulphocyanide of potassium (KCyS) is made by simply boiling sulphur with a solution of pure cyanide of potassium. It is used in commerce as the basis (with mercury) for the manufacture of the dangerous little fire cones, known as Pharaoh's serpents. When a small quantity of the sulphocyanide of potassium is introduced beneath the skin of the frog, the muscular system becomes entirely paralysed to every other stimulus than that transmitted through the nerves. Electricity applied directly to the muscle now produces no effect, but still exerts its power upon the muscle when applied directly to the nerves distributed to the muscle.

The real nature and composition of woorara (curare) continue unknown. It is an extract of one or several vegetables, and probably contains also several animal products. The Indians dip the points of their arrows in it and thus kill their foes by the slightest wounds. They use it also for hunting purposes, experience having taught them its perfect innocuousness when introduced into the stomach, notwithstanding its deadly effects upon the blood. The flesh of animals killed by woorara is eaten with perfect impunity, while if the poison be extracted from the stomach of an animal to which it had been administered in its food, and injected into the blood of another animal, it will promptly exhibit its toxic effect; proof that the immunity which the stomach enjoys, is not due to neutralisation of the poison by the gastric juice, but to refusal to absorb it. In this respect it resembles the poison of snakes, on which account its active principle has been supposed to be the venom of the crotalus (Fournié).

When a small quantity of curare is introduced beneath the skin of an animal, it paralyses all the motor nerves, but has no effect whatever upon the sensitive nerves, or upon the muscles. Electricity or other excitant may now be applied to the nerves without the least effect upon the muscle, but the muscle still continues to respond to direct excitation of its substance. Curare acts by first destroying the irritability of the end plates of the nerves within the muscles. Some of the derivatives of strychnia, ethylstrychnia, methylstrychnia, etc., produce the same effect.

Thus is absolutely determined the question of the independence of muscular contractility and its inherence in muscular tissue itself. But the solution of this question in no way invalidates the fact that muscle never contracts spontaneously, but always, and only, in obedience to some force outside of the muscle substance. It is only within a very few years that the heart has been proven to be no exception to this absolute law. Bernstein found that if the ventricle be compressed transversely in the middle with a pair of narrow-bladed forceps, the part beyond the line of compression remains absolutely inactive, though its nutrition is perfectly provided for by the persistence of the normal movements in the rest of the heart, and Bowditch concludes from his experiments that "when after transverse compression of the ventricle, the apex, at first brought to rest, recommences to beat, this renewal of activity depends upon the restoration of an imperfectly destroyed connection between the apex and the motor apparatus at the base of the heart."

The Generation of Heat.

Muscle, in contracting, develops heat. Every one is familiar with the fact that the temperature of the body increases during exercise. In the absence of fire, we depend upon exercise to furnish means of sustaining the body heat under exposure to cold. But exercise also increases the activity of the circulation, of respiration, etc., as more probable sources of the origin of heat. To determine whether muscle developed heat, and if so, its exact amount, Becquerel and Brechet made use of an instrument known as a thermo-multiplicator, so constructed as to cause wide deviations of a needle under fractions of a degree of temperature. A needle connected with the apparatus was now stuck into the biceps muscle of a man. When the biceps contracted, it registered a deviation corresponding to an increase of 1° C. Helmholtz experimented with frog's muscle connected with the body only by its nerve; removed, thus, from the circulation; and observed, by means of a very sensitive multiplicator, a deviation, during contraction, corresponding to an elevation of 0.1° C. In a frog's muscle a single contraction may develop 0.005° C., which tetanus may increase to 0.15° C. Béclard, Thyry and Meyerstein, Heidenhain, and, more recently, Fick, have all, by numerous experiments, demonstrated the increase of temperature in the contraction of muscle. Fick observed that when a muscle was allowed to extend itself with the weight, which it had just lifted, still attached to it, it gave out more heat than when it was allowed to extend itself without the weight, that is, with the weight removed at the maximum of contraction. For, in the sinking of the weight, while muscle regains its former length, the mechanical work is changed into an equivalent quantity of heat. This fact, Cyon remarks, can only be construed as an irresistible substantiation of the law of the conservation of force in muscular work. So, too, it has been observed that if a muscle be held down during contraction, or during the effort of contraction, more heat is developed; the chemical force in the muscle not being able to expend itself in mechanical work, appears as heat.

The Generation of Electricity.

Lastly, muscle, in contracting, develops electricity.

Rigor Mortis.

We may take up now the changes which muscle undergoes at and after death. It is a familiar fact that death of all the tissues does not take place simultaneously. For a long time after volitional or reflex control has been lost, by suspension of volition or reflex action, a muscle will still continue to respond to artificial stimulus. The muscles of cold blooded animals remain irritable for 8–10 days after the death of the animals, and under favorable circumstances, much longer. Thus my colleague, Dr. Longworth, reported to our Academy of Medicine, the continuing pulsation of the heart of a boa constrictor twenty-one days after it had been sent in dead from the Zoological Garden for purpose of post-mortem examination, and Redi saw contractility persist in a tortoise twenty-three days after death. But the muscles of warm blooded animals lose their irritability in a few hours, or at most, in a few days. The muscles of birds cease to respond to irritation sooner than those of mammals.

The precise time at which muscle irritability is lost, depends then upon the nature of the animal. It depends also upon surrounding conditions. Thus it is preserved longest at a temperature of 0° C.; a lower temperature freezes muscle and thus speedily destroys its irritability, and a much higher temperature hastens chemical change and thus exercises the same effect.

The death of muscle is characterised by a peculiar change in its substance. It becomes gradually more dense and less extensible. When this stage has wholly developed, muscle is said to be in the stage of cadaveric rigidity or rigor mortis. The immediate cause of these physical changes is the coagulation of the myosin, or muscle protoplasm. Myosin clots after death just as fibrin clots in the blood, and thus changes the consistency of muscle substance. The members of the body must be composed shortly after death to anticipate these changes by a fixation in the position in which it is intended they shall remain. For, after rigidity is developed, the posture of the body, or the position of members, can be changed only with considerable force.

Rigidity first establishes itself in the muscles of the neck and jaws, next in those of the trunk and lastly in those of the upper and lower extremities, and it is in this order or sequence that it gradually disappears to putrefactive change. It never occurs immediately after death, and is never entirely absent, though it may be comparatively slight in degree. Involuntary muscle experiences the same change, but at a later period. The very last muscle to surrender to rigor mortis is the right auricle of the heart, and because this fact was first noticed by Haller, this organ was complimentarily designated the "*ultimum moriens Halleri.*"

Such radical change occurs in muscle substance when undergoing rigor mortis, that it is only at the commencement of this process that its irritability can be restored by the transfusion of fresh blood. Preyer was able, however, by dissolving the coagulated myosin with a solution of common salt, and then injecting blood, to restore irritability to muscle in cadaveric rigidity. This recovery of tone was, of course, due to the fact that all the myosin does not coagulate at once; enough for purposes of demonstration still remains fluid, and able to act, when relieved from the clogging action of the coagulum about it.

Post-mortem rigidity sets in very speedily in muscles whose tone has been exhausted just before death, as in hunted animals, or after poisoning with strychnia, tetanus from septic disease, or other cause. It is stated by Sommer that it never manifests itself sooner than seven minutes or later than ten hours. Although army surgeons have contended, from observations of the postures of soldiers killed on the field of battle, that rigidity is occasionally immediate, it is known that some interval of time always intervenes. But in cases of very sudden death the interval is very short. As a rule, the more slowly it develops, the longer it lasts. In cases of death by stroke of lightning or poisoning by prussic acid, its persistence is so short as to have given rise to the erroneous belief that it had not occurred at all. We know of no agent that may temporarily induce it after the manner of the drug which the friar gave to Juliet, that

> "Each part deprived of supple government,
> Shall stiff and stark and cold appear like death."

Post-Mortem Changes in Muscle.

Very curious changes sometimes occur in muscle after death. In the presence of much moisture, bodies are occasionally completely saponified, converted into adipocire, and are thus indefinitely preserved. Or, muscle, with other soft parts, may become dried up, mummified, and be thus preserved for thousands of years. Both these processes, as well as that of calcification (lithopædion), may occur also in the fœtus in utero. But, in the rule, muscle substance undergoes gradual liquefaction and resolution by ordinary putrefactive changes. But all the muscles do not suffer dissolution to the same degree. Thus the walls of the aorta persist long after the smaller vessels and the voluntary muscles have disappeared. The tissue or structure which survives, or rather persists, the longest, is the uterus, and it is to call your attention to this fact, which is of great value from a medico-legal point of view, that I make mention of a subject not strictly physiological. The uterus remains fresh and firm long after destruction of all other soft parts in the body. In the midst of universal decomposition it may still be removed from the body in its entirety, be opened and examined, and thus the presence or absence of pregnancy at or prior to death, established. The uterus of the new-born child persists in the same way. In his monumental work on Legal Medicine, Casper details cases of extreme interest in which the persistence and appearance of the uterus furnished positive evidence concerning conditions at the time of death.

The Fuel of Muscle.

The muscle machinery is no more capable of action without food than a steam engine without fuel, and the promptitude and power of muscular action depends, as in the machine, upon two factors: (1), upon the character of the fuel, and (2), upon the capacity of the muscle to convert latent into active force. The fuel from which the most force can be evolved is that which contains the most combustible material. The most combustible material (that is least expensive) is carbon. The fuel which contains the most carbon is coal, hence coal is the best fuel for the engine. The food which contains the most carbon is fat, and the various hydrocarbons, hence these aliments form the best fuel for muscular work. It has always been maintained up to very recent years that muscle consumed its own substance in its work, but this view was easily disproven by the observation that the products of muscular work are not products of muscular consumption. Muscle protoplasm is largely composed, as we have seen, of myosin, a pecular albumenoid substance, which occupies a place between fibrin and globulin. Oxidation of myosin, which with all the albumenoids is a nitrogenised matter, must yield nitrogenised products (ŭrea) in the excretions. But observation has shown that the urea is not increased in the urine as the result of muscular work. This conclusion has been reached from many directions, but nowhere so decisively as from the observations of Fick and Wiscilenus, who ascended, fasting, a high mountain in the Bernese Alps, carefully measuring the urine voided at every stage of progress, for its quantity of urea. The quantity of urea was not increased by this severe physical exercise, but the exhalation of carbonic acid gas from the lungs and skin was very markedly increased, proof that the material used as fuel was not the muscle substance itself, but the hydrocarbons of the blood. Indeed, Mayer has made a calculation showing that if muscle consumed itself in action the whole muscular system would be burnt up (oxidised) in just eighty days.

But though muscle machinery does not use up itself as fuel any more than any other engine, it does, like every other engine, undergo the wear and tear of daily use and thus experience waste in slight degree. That this waste may be repaired and the physiological integrity of the muscles preserved, nitrogenous food is also a necessity.

The Arab, says Donders, never lets his horse eat grass and hay to satiety. Its chief food is barley, and in the wilderness it gets milk, and if great effort is required, even camels flesh. A super-abundance of nitrogenous food is found for animals in corn, which, notwithstanding its excess of hydro-carbons, contains more albuminates than any other vegetable food. Oats, too, furnish horses an abundance of nitrogenous matter, and jockeys have a saying, on witnessing spirited work in horses, that they "feel their oats."

The Oxygen Supply.

The food thus furnishes the oxidisable material. Then muscle must also receive abundant supply of oxygen. We have already seen, that this supply is brought to muscle by the blood, which reaches it red and leaves it blue. If the muscle be at rest, however, the blood is so little deoxygenated that its escaping blood preserves its arterial hue. It is said that oxygen administered roughly, as by the injection of a highly oxygenated substance, permanganate of potash, for instance, will restore irritability to a dying muscle, and it is well known that the transfusion of fresh blood will, by means of its oxygen, effect this result up to, and even after the commencement of, cadaveric rigidity.

Dependence of Muscle upon Blood.

The necessity of a continuous supply of material for consumption (food), and material for consuming (oxygen), by the blood, is conclusively demonstrated by the observation of the effects attending ligation of the vessels supplying muscles. Thus Longet tied the abdominal aorta in five dogs and found that voluntary motion ceased in about a quarter of an hour, and response to artificial stimulus in two and a quarter hours. When the ligature was removed, irritability to stimulus, and afterwards voluntary motion, shortly returned. Brown-Séquard made some similar experiments of more striking nature upon the human body. In the cases of two decapitated criminals, he transfused fresh blood into the arteries of the hand, thirteen hours and ten minutes after death, when all muscular irritability had disappeared, and cadaveric rigidity was quite marked, and found that it reappeared and could be demonstrated in all but two of the muscles of the hand. On a subsequent occasion, he used the defibrinated blood of the dog with the same effect (Flint).

The Muscles as Levers.

Let us now look at the muscles from a purely mechanical point of view, viz., as levers. Those of us who are at all acquainted with the laws of mechanics are aware that there are three different classes of levers. The first is represented in using the common crowbar, or in working the pump handle, or in raising coals with a poker in a grate. The fulcrum rests between the power and the weight. Though there is in this form of lever considerable power, there is not much range of movement. The chief advantage of this lever is celerity of action. A typical illustration of this form of lever in the body is the action of the muscles which move the head upon the spine. The muscles of the neck constitute the power, the head is the weight, and the spine is the fulcrum.

In a lever of the second class, the weight is between the power and the fulcrum, as in the case of trundling the common wheelbarrow. Here there is great power, but little velocity, and less range. The best, and almost the only, example of this lever in the body, is the action of the tendon of Achilles in lifting the whole body in walking. The muscle of the calf form the power, the body is the weight, and the toes are the fulcra.

In the lever of the third class the power is between the weight and the fulcrum. It is represented in lifting a ladder up against, or away from, a wall. There is here but little advantage for power, there is less velocity, but there is wide range. The free end of the ladder has enormous sweep. The lever of the third class is the feeblest of all the levers, but every thing here is sacrificed to range. This is by far the most common form of lever in the body, and is typically represented in the action of the biceps brachialis.

The Absolute Power of Muscle.

The absolute power of muscle is dependent, as would have been inferred, upon its bulk, as exhibited on cross section, and is determined by observing the weight which it will lift. It has been observed that the power of contraction is at its maximum on the beginning of shortening, and thus

Weber has been able to fix the absolute power of one square centimetre of frogs muscle (hyoglossus), under the most favorable circumstances at 0.692 kilogrammes (24 oz.). Rosenthal succeeded later in obtaining better results, viz., for the same quantity of muscle a little over one kilogramme (35 oz.). Weber found that muscle exerted its maximum effect when he loaded the same piece of muscle with only 450 grammes (15 oz.). The muscle then lifted 93 times its weight 15 millimeters (006 in.) high. In subsequent experimentation on man, Weber found that the absolute power of human muscle is very much greater. Thus a square centimeter (0.4 in.) of the gastrocnemius muscle of man has an absolute power of 700–1087 grm. (24–38oz.). Henke and Koster have, also, obtained better results, observing that a square centimeter of muscle from the thigh had a power 5.9 kilogrammes (215 oz.) and from the arm of 8 kilogrammes (282 oz.), a difference, as Bruecke observes, which was clearly due to difference in the muscular power of the individuals under observation.

The Power of Muscle in General.

The general power or force of muscles may be readily estimated by means of an instrument first devised by Regnier, the dynamometer, which consists of a steel spring whose compression (by the hand or other group of muscles), moves a needle along a scale graduated to represent equivalents of weight. This instrument of precision is of great value in clinical medicine in enabling the physician to accurately guage the effects of treatment of paralysed muscles and has enabled physiologists to make the observation that the muscles differ in force in different individuals, and in different muscles in the same individual at different times. Thus Koster found that the power from the same sections, was for the biceps brachialis 17 kilogrammes, for the gastrocnemius 10 kilogrammes and for the posterior tibial only 2 kilogrammes. The difference in different individuals is generally determined after the method first employed by Regnier, which consists in lifting a weight from the ground between the feet. Quetelet called the force thus employed the renal force, and remarked that in youth it is very slight; it increases rapidly up to the age of 17 or 18 and attains its maximum at 25 years. It now remains stationary for a time and then declines markedly towards 40 years. It is always much less in woman than in man. Desaguliers states that the weakest men in health may lift 125 lbs., and the strongest of ordinary men, 400 lbs. Topham, a so-called Sampson, could lift 800 lbs.

Differences in the Sexes.

It is a subject of daily observation that the female of most animals is capable, though of less powerful, of more sustained effort. And this observation is supported by anatomical and physiological differences in the construction and action of the muscles. The action of muscular fibres has been not inaptly compared by Milne Edwards to the work of a number of laborers. The fibres are laborers in long parallel lines. They do not all pull at once or with the same degree of exertion. Hence the greater the number of fibres the greater the number of rested or resting fibres. The muscular fibres in the female, though individually smaller, are numerically greater, and hence the capacity for greater sustentation of effort.

Differences in Different Animals.

C. Sachs has shown that the muscle caskets are smaller in warm than in cold blooded animals, and smaller in cold blooded animals than in anthropods. In the smaller pieces the physiological surface of tissue is increased and the energy of metamorphosis is greater. Hence the mechanical effects of smaller fibres is heightened, "just as a bundle of magnets has a greater effect than one massive magnet of the same weight." The force of the muscle of mammals is hence greater than that of the frog.

The remarkable duration and sustentation of muscular effort in birds thus also finds satisfactory explanation. Montague, a celebrated ormithologist, estimates that hawks fly at the rate of 150 miles an hour and various birds often travel 600 to 1000 miles without food in their winter and summer migrations. But it is in insects, in which the muscle caskets have been discovered to be minute structures distinctly suspended in fluid, that the force of contraction is greatest in proportion to their size. Thus Dunglison states that the lucanus cervus, or stag-beetle, has been known to gnaw a hole, of an inch diameter, in the side of an iron canister in which it had been confined, and the same author calls attention to the persistence and apparent ease with which flies will keep up with the fleetest race horse, sweeping large circles about him all the time. The stridulations (scrapings of wing covers) made by crickets and grasshoppers can be heard a mile, whence it is estimated that if man could emit sounds whose intensity should be proportionate to his size, he could make himself heard all around the earth.

The Velocity and Delicacy of Muscular Action.

We may not take final leave of the properties of muscle without calling attention to the readiness of its response to stimulus, its capacity for swift repetition of contraction, and the degree of delicacy and accuracy of its action under proper cultivation. The ready response of muscle has been clearly shown by Kronecker and Stirling in their demonstrations that muscle replies to stimuli, which reach their maximum in the nerve in less than the $\frac{1}{500000}$ part of a second. And as to the capacity for swift repetition of contraction, these same experimenters quote the observations of Ranvier, who remarked that the pale muscle of the rabbit could indicate 357 single contractions in a second, and of Marey that the common horse-fly can make voluntarily 330 movements of the wing in a second. The musical tone emitted by the contraction of muscle gives an accurate estimate of the rapidity of muscular movement. A certain tone corresponds, of course, to a certain number of vibrations, and hence it is calculated that the wings of insects strike the air even many thousand times every second. The finest muscular movements in man, are those which change the position and tension of the vocal cords. Müller has observed that there are at least 240 different states of tension of the vocal cords, and as the whole variation is not more than one-fifth of an inch, the variation required to pass from one interval to another will not be more than $\frac{1}{1200}$ of an inch.

The quick, deft and delicate play of muscles is hardly anywhere better exhibited in man than in the modulations of the voice, in the shades of expression of the face, and in the infinite variety of gesticulation. Thus:—

"With hurried voice and eager look
Fear not, he said, * * *
* * * but there the accents clung
In tremor to his faltering tongue." Scott.

"The arched and polished forehead," says Sir Charles Bell, "terminated by the distinct line of the brow, is a table, on which we may see written in perishable characters, but distinct while they continue, the prevailing cast of thought."

"You may sometimes trace
A feeling in each footstep, as disclosed
By Sallust in his Cataline who, chased
By all the demons of all passions showed
Their work even by the way in which he trode." **Byron.**

LECTURE XI.

NERVE AND ITS PROPERTIES.

CONTENTS.

The Prime Function of Nervous Tissue—Subordination to Other Tissues—Independence of Nerve Force—Genesis of Nerve Force—Arrangement of Nerve Tissue—White and Gray Matter—The Cerebro-Spinal and Sympathetic Systems—The Nerve Cells—The Nerve Fibres—The Neurilemma—The Axis Cylinder—The Gray Fibres—The Properties of Nerves—Terminations of Sensitive Nerves—Terminations of Motor Nerves—Course of Nerve Fibres—Identity of Nerve Fibres—Indifference of Direction of Nerve Force—The Chemistry of Nerve Tissue—The Action of Electricity upon Nerve Tissue—The Nature of Nerve Force—Rate of Conduction of Nerve Force—Nerve Force and Electricity—Comparative Velocity of Nerve and Other Forms of Force—The Reception and Perception of Impressions—Ancient Significance of Nerves—The Effects of Use, Disuse and Age.

The primary object of the nervous tissue is to link together different and often widely distant structures. The nervous system is thus the supreme regulator of the actions of the body. It secures harmonious and consentaneous, or coördinated, operations. Thus, if muscular activity is to be increased (exercised), the muscle substance must needs have more fuel in the way of additional supply of blood; it must also have more oxygen to effect the consumption of the fuel and thus the liberation of additional force. Hence increased muscular activity implies accelerated circulation and accelerated respiration. It is the function of the nervous system to secure this consentaneous and correspondent activity on the part of the heart and lungs as well as on the part of the muscle. The nervous system has, at the same time, to regulate the activity of the secretory organs to provide for the escape of the products of combustion. Complexity of organisation implies, therefore, a nervous system in high degree of development. An animal takes rank in the animal scale, according to the degree of development of its nervous system, that is, according to the quantity and quality of its nervous tissue.

The Nervous, Subsidary to Other Tissues.

But so much stress has been laid upon the supremacy of the nervous system that we are apt to forget that the rest of the animal was not constructed for the nervous system; the nervous system is constructed rather for the benefit of the animal. In fact, the nervous system stands towards the rest of the body, much in the light of telegraphy to the inhabitants of a country. It signalises wants and supplies, regulates transmissions, warns of dangers and furnishes intelligence. We look back with a feeling of pity and contempt, upon that state of society which enjoyed no system of telegraphy, no means of rapid communication, just as we look down upon animals not endowed with nervous tissue, yet we may not forget that such states of society, and such kinds of animals, did and do exist. The nervous system is thus an addendum to a higher grade of development. We may not, therefore, look upon the body as a collection of cells attached to the nervous tissue like the leaves, for example, upon the trunk and twigs of a tree. On the contrary, it is the nervous system which is attached to the cells. The nerve fibres are to be looked upon as offshoots from the cells for the purpose of association and interaction.

Independence of Nerve Force.

It was once believed, is taught now by some metaphysicians, that nerve force is born in nerve centres and is sent through nerve fibres to muscles, for instance, where it acts as motion. That is, that motion is only a transformed nerve force. But the physiologist can not accept such a doctrine. The nerve force is not the fuel for the muscle. The blood, which is the prepared food, is the fuel that furnishes the muscle with force. The nerve force is simply the excitant of the muscle. A very small amount of nerve force suffices to induce a very great amount of muscular force. Muscle is a machine, as we have seen, like an engine. It stands ready to act. There is steam in the boiler, that is, there is blood in its substance. Still the engine does not move. The nerve force is the hand that opens the throttle and thus causes the machinery to move. I might make this point plainer by likening the parts of the body to different branches of a great army out upon the field. The nervous system is the system of telegraphy which directs the movements of the army. But no one would claim that the movements of the army, were transformations or transubstantiations of the force of electricity in the battery of the telegraph.

Genesis of Nerve Force.

The nerve force is generated in nerve cells and is conducted along nerve fibres or tubes. The study of the nervous system divides itself, thus, physiologically, into the study of the generators and the conductors. Cells never conduct and fibres never generate. Of course, in using the term generate, it is not meant to imply the creation of a new force. Such a conception is unscientific, that is, false. The nerve cells generate nerve force in the sense in which the cups of a galvanic battery generate electricity. The electricity from galvanism is the result of chemical force which, in turn, is liberated from force latent in metals,etc., stored up in the past. So the nerve cells are simply means of transforming latent force in the blood into nerve force. We return again to the galvanic battery.

Arrangement of Nerve Tissue.

The nervous system, we find to be arranged like the telegraph system of a nation or state. There is a great central battery in the capital, represented in the brain; there are smaller batteries in smaller cities, as in the separate collections of nerve cells (ganglions) in different organs, and where distances are great, there are reenforcing batteries, as along the sympathetic and pneumogastric nerves. The connecting wires are represented by the nerve tubes.

The Color of Nerve Tissue.

The nerve cells, *en masse*, present a more or less grayish hue, while the tubes, *en masse*, present a distinct white color. Hence the terms gray matter and white matter. The outside (cortex) of the brain and the inside of the spinal cord are mainly composed of cells, gray matter, while the interior mass of the brain and the exterior of the cord, are composed of nerve fibres, white matter. The great ganglia at the base of the brain and the smaller ganglia scattered over the body, everywhere, are composed of both cells and fibres, and show colors according to the relative arrangement or predominance of one or other structure.

The Cerebro-Spinal and Sympathetic Systems.

Finally, the mass of nerve substance accumulated in the cranial cavity (the brain), and in the great tube formed by the imposition above each other of the arches of the vertebræ (the spinal cord), together with all the nerves (cranial and spinal) which issue from their base and sides, constitute the cerebro-spinal system (voluntary), presiding over animal life; and the ganglionic masses, disposed along each side of the spinal column and extending into the cavity of the cranium, connected with each other and with the cerebro-spinal nerves by commissures and supplying motor and sensitive structures with nerve filaments, constitute the sympathetic (involuntary) system, presiding over vegetative life.

The Nerve Cells.

The nerve cells are readily recognised under the microscope by their irregular, often almost fantastic, shape, their bright nucleus and nucleolus, the amount of colored protoplasm (pigment) which they contain, and by the prolongations which issue from their circumference. The prolongations are known as poles. We observe, thus, unipolar, bipolar, multipolar cells. Apolar cells are probably artificial creations that is, they are results of accidents in the examination. Else, having no use, they would have to be regarded as foreign bodies or parasites.

We may mostly recognise among the poles one which seems to be composed of the essential element only of the nerve fibre. It is, in fact, the commencing nerve fibre. Some of these fibres pass out to the periphery as nerves, others pass to other cells, connecting them, as commissures. The great transverse bridge of the brain, the corpus callosum, is made up, for the most part, of these internuncial fibers, connecting the cerebral hemispheres.

The Nerve Fibres.

Nerves are bundles of nerve fibres. The ultimate nerve fibre is composed of three parts; the investing membrane neurilemma, or tubular sheath; the medulla or white substance of Schwann; and the essential element or axis cylinder.

The Tubular Sheath,

or neurilemma, is an exceedingly delicate, translucent, but highly resistant and elastic membrane which envelops the exterior of the nerve throughout its course. It is absent at its inception from the nerve cell, it is absent also in places where the nerve is already sufficiently protected, in cavities containing only nerves, as in the substance (white matter) of the brain, and is absent again where the nerve passes to its ultimate distribution.

The White Substance of Schwann,

unfortunately named the medulla, as it does not occupy the centre of the tube, like the medulla of bone, is the gelatinous, translucent, substance, which composes the bulk of the nerve fibre. Shortly after death of the nerve, it coagulates to an opaque, white mass, and gives to the nerve a quite characteristic, varicose, appearance. The medulla is also absent in central nerves and at the beginning and end of nerves.

The Axis Cylinder,

or axial band, is the central, rather flattened band of clear, glassy, jelly-like matter, which occupies the centre of the nerve tube. The axis cylinder is the sole essential conducting element. The nerve issues from the cell as the axis cylinder only, and the medulla and the tubular sheath are subsequent additions of structure. At its final distribution, the tubular sheath and medulla both disappear, and the axis cylinder alone passes to the substance of the muscle, gland cell, hair bulb, or other structure, destined to receive it. Just before its termination, the nerve divides into a number of branches, each commencing with a constriction, and then expanding to the full size of the original trunk. The axis cylinder throughout exhibits fine longitudinal striæ or lines, which are supposed to represent fibrillæ, like the subdivisions of muscle fibre, and which are regarded by some histologists (Schultze) as the ultimate elements of composition. When staining solutions, aniline, carmine, etc., are brought into contact with a piece of living nerve under the microscope, it is the axis cylinder alone which is colored.

The Gray Fibres.

Besides these so-called medullated fibres, there exists a different variety of very delicate fibres, whose interior consists of a uniform, grayish matter, and whose rather thick sheath is provided with distinct nuclei. Such fibres are found only in the sympathetic system. They are commonly known, from their discoverer, as the fibres of Remak.

Most nerve fibres of the sympathetic system, however, are constituted upon the same plan as those of the cerebro-spinal axis, and the several parts are roughly likened to the constituents of the sub-marine cables; the envelop representing the neurilemma; the rubber or silk insulating matter, the medulla; and the conducting wire, the axis cylinder.

The Properties of Nerves.

It is the function of some of the nerves to conduct from the nerve cells, motion, and of other nerves to conduct to the cells, sensation. Other nerves passing to and from the various glands, to regulate secretion, are known as secretory nerves, and still other nerves passing to the walls of blood-vessels, to regulate their calibre, are known as vaso-motor nerves. The secretory and vaso-motor nerves, including fibres of motion and sensation, are described with the rest as motory and sensory nerves. Motor and sensitive nerves are such exclusively at their origin from motor and sensitive nerve cells, but shortly after emergence from the brain, spinal cord, or ganglion, the fibres commingle to constitute what are known as mixed nerves.

Terminations of Sensitive Nerve Fibres.

The nerve fibres issue, as we have seen, from the nerve cells, and are to be regarded as prolongations from the nerve cells to the periphery, where they terminate in special structures.

The sensitive nerves terminate in a number of peculiar bodies, corpuscles of Pacini or Vater, corpuscles of Meissner and Wagner (tactile corpuscles), and corpuscles of Krause. These bodies consist of rounded or ovoid layers of connective tissue, in the interior of which, or upon the exterior of which, the axis cylinder ends. In the case of the large Pacinian bodies, located in the tendons, and especially abundant about the mesentery, the axis cylinder enters its base and divides, in its central cavity, like a fork with prongs, into two or three branches, which finally terminate in granular expansions. In the case of the smaller tactile corpuscles, found in such abundance in the papillæ in the cutis vera, the axis cylinder is wound spirally about the exterior to finally terminate in a point of extreme tenuity. In the still smaller corpuscles of Krause, found in the tongue, conjunctiva, glans penis and clitoridis, and in the nipple, surfaces of extreme sensitiveness, the axis cylinder penetrates the base and terminates in the interior in a loose coil.

All these bodies would seem to exist for the purpose, in the first place, of acting as *points d'appui*, points of support, and, secondly, of increasing the area of surface for the termination of the nerve fibre. They officiate something like the thickenings of epidermis on the feet, commonly known as corns. Though the epidermic mass has in itself no sensation, it transmits pressure from every part of its surface to the few nerve fibres at its base, and thus is a conductor of sensation, which often amounts to positive pain.

But the greater number of the sensitive nerve fibres pass to terminate in the hair bulbs. It is a well-known fact that we experience tactile sensation before absolute contact with the skin is effected. The touch is felt by the hairs, which so uniformly cover the whole surface of the body. The hairs, of course, simply transmit pressure to the nerve endings in their bulbs. These endings are especially abundant about the face, and, in the case of some animals, are peculiarly large and sensitive about the various vibrissae or whiskers. Thus, a cat will readily wander about a darkened chamber, guided by the exercise of the fine sense of touch in its whiskers, which correspond to the antennae of insect life. It is said that a kitten will thus find its way even though perfectly blind. But if, in addition to its loss of sight, it is made to lose its whiskers, it will knock its head against every obstacle.

Nerve fibres terminate in the glands by effecting with the secreting cells the most intimate union. Ends of nerve fibres have been absolutely traced by Pflueger to the nucleoli of the cells composing the salivary gland and the pancreas.

Terminations of Motor Nerve Fibres.

In smooth muscle, nerve fibres have been traced by Frankenhæuser and Arnold into very fine networks, which connect together the nucleoli of the muscle fibres.

The final distribution of the nerves in striped muscle is still, however, a question of doubt. It is conceded by all observers that the nerve fibre, after penetration of a muscular mass, splits into a number of branches, that it then loses its medulla, and that a number of nuclei present themselves upon the still persisting neurilemma. These nuclei, accumulated in mass as the nerve fibre approaches the muscle fibre, fuse with accumulated nuclei in the sarcolemma of muscle fibre, to constitute a disk or plate upon the surface of the muscle fibre. So far, there is general agreement. The disagreement concerns the ultimate disposition of the nerve fibre. While Doyère, Krause and Engelmann maintain that the muscle plate is the end of the nerve fibre, Kühne and Gerlach claim that the axis cylinder afterwards leaves the muscle plate and passes in to make immediate connection with the muscle protoplasm. From among the many opinions expressed by the most competent observers, we elicit the fact that the difference concerns the question whether the axis cylinder touches the muscle fibre at one point only, or whether it absolutely fuses with it within its sarcolemma. This latter view is probably most correct; but the muscle may not be regarded as the end of, or attachment to, the nerve, as Gerlach has advocated; the true expression of the fact is that the nerve is an offshoot or an addendum to the muscle.

Course of Nerve Fibres.

Except at their final termination, nerve fibres never divide or anastomose (if we may use such an expression of tubes whose contents are more or less solid) with each other. Each fibre pursues a course, as straight as may be, from the centre to the periphery, or vice versa. To this anatomical fact is due the precise circumscription or localisation of sensation or motion. A motor nerve fibre, irritated anywhere in its course, produces spasmodic contraction in the muscle or part of muscle to which it is distributed, and nowhere else. So irritation of a sensitive nerve, in any part of its course, causes sensation to be perceived at, or referred to, the peripheral distribution of the nerve, and nowhere else. A blow received upon the ulnar nerve at the elbow, for instance, is felt as a tingling sensation in both sides of the little finger and the little finger side of the ring finger, surfaces receiving the entire peripheral distribution of this nerve. So a tumor or foreign body pressing upon the intracranial trunk of the fifth pair of nerves, may be the cause of the intense pain of tic-douloureux experienced in the face. Romberg reports a most instructive case illustrative of this point. It was a case in which the patient had suffered for years previous to his death from most distressing and frequent paroxysms of facial neuralgia, the cause of which, as revealed on post-mortem examination, was an aneurismal enlargement of the carotid artery, which made direct pressure upon the fifth nerve in the vicinity of the Casserian ganglion. The aneurism had surmounted the process of bone on the lateral aspect of the body of the sphenoid, which process Hilton has signalised and denominated the "carotid process," having to exercise "the important function of preventing the artery, during its pulsations, from pressing on the second division of the fifth—a nerve endowed with such exquisite sensibility, that the slightest injury or pressure would lead to the production of serious pain and distress."

So definitely and distinctly are sensations referred to the periphery of nerves, that individuals who have suffered amputation will imagine, on experiencing irritation in the stump, the presence of the foot or hand, and cases are recorded in which patients have thus injured the parts in the attempt to step upon an ununited stump of the leg. This distressing feeling, or imagination of feeling, in absent fingers or toes is, as a rule, gradually corrected by education or habit, but it has persisted in some cases for 15–20 years. It is also because of this distinct localisation of sensation, that individuals who have undergone plastic operations, as in the transplantation of skin from the forehead for the creation of a nose, still refer impressions received upon the nose to the forehead. Of course, this reference only applies to cases in which cutaneous continuity has been maintained, as in the stem of the graft which is twisted upon itself, not dissevered, to become the root of the nose. The facetious comment of Hudibras, therefore, regarding absolute ablation of skin and transplantation at distant points, finds no foundation in fact.

Identity of Nerve Fibres.

The nerve fibres are thus so distinctly separated into conductors of motion and sensation as to preserve their characteristics throughout their course. Nevertheless, there is no anatomical or chemical difference between motor and sensitive nerves. It is the connection of a nerve fibre, and not its construction, which determines its use. A nerve connected with a muscle is a motor nerve; a nerve connected with a gland is a secretory nerve; a nerve connected with a sensitive surface is a sensitive nerve. So the nerves are compared to battery wires which may conduct force to ring a bell, show a light, or write a message, according to the construction of the end apparatus. Experiments have been made to exhibit this indifference of the nerve fibre, so to speak, by transferring the cut end of a motor fibre to the cut end of a sensitive fibre, and securing or awaiting union of the apposed ends. Philipeaux and Vulpian thus observed after union of the lingual (sensitive) and hypoglossal (motor) nerves of the tongue, that irritation of the lingual produced contraction in the tongue. It is only fair to state, however, that the results of later experiments by Vulpian have left this question somewhat in doubt. For Vulpian observed that contraction of the tongue supervened upon irritation of the lingual, thus united to the hypoglossal, only when the chorda tympani fibres in the lingual remained intact. When the chorda tympani was divided, the contractions did not supervene. These experiments, therefore, simply prove that motor nerves will conduct for each other.

Indifference of Direction of Nerve Force.

It is, however, a clearly established fact that nerve fibres will conduct just the same in both directions. That is, if a nerve fibre be exsected and reversed, so that its peripheral end is now central, nerve force will travel along it, after union of the ends, just as before. This fact was very strikingly demonstrated by Paul Bert, who inserted and fastened the denuded tip of a rat's tail into an incision over the centre of its back. After firm union had been secured, he separated the tail from the rump of the animal by division of its base. The positions of the free and fastened ends were now exactly the reverse of the natural condition. At the end of three months, irritation of the end of the tail was evidently perceived, and at the end of six months, sensation was as distinct as before the operation. The sensitive nerve now conducted the impression in a reverse direction.

The Chemistry of Nerve Tissue.

Four-fifths of nervous tissue is water, and of the remaining fifth, the most essential element part is the peculiar albumenoid substance, known as lecithine, which is remarkable for the amount of phosphorus which it contains. Lecithin is a nitrogenous, organic, phosphorised acid, a glycerinphosphoric acid, which is made up of radical fatty acids (stearic, oleic, etc., acids), and a derivative of ammonia (neurine). Lecithin and cerebrin, an additional albumenoid body of somewhat similar constitution (but more easily soluble in alcohol and less easily in ether), give to nerve tissue its physical characteristics. Both these substances swell in water, and thus form the drops of medullary tissue which exude from the nerve on microscopic examination. Both these substances more nearly resemble casein (in easy solubility in dilute acids and solutions of soda) than any other familiar albumenoid body. The predominance of phosphorus also makes itself manifest in the mineral salts entering into the composition of nerve tissue. The analyses of Bibra show that of 100 parts of mineral matter from the human brain, the phosphates of potassium, sodium, iron, lime and magnesium form 84.5 parts. This presence of phosphorus, in such quantities, in all parts of nervous matter, is the fact of highest interest from a chemical point of view.

That chemical processes are continually at work in living nerves is proven by the existence of electric currents in the nerves. In the absence of any other cause, electricity cannot exist, or be developed, without chemical action. The fact, too, that nerve fibres degenerate so soon as they are separated from their central connections, also proves the presence of chemical action. We may surmise that the chemical processes in nerve fibres consist essentially in oxidation of the non-nitrogenous elements of the blood, whose chief product is carbonic acid gas, but we have as yet no positive and definite knowledge concerning the fuel of nerve tissue.

The Action of Electricity upon Nerve Tissue.

Nerve fibre differs from muscle in not manifesting the action of stimulants or irritants in any visible effects. Nerve fibre does not shrink, contract, or undergo, under irritation, any perceptible change. Nerve fibre exhibits its susceptibility to irritants only in the effects produced in the structures innervated; that is, in the contraction of muscle, secretion of glands, perceptions of impressions of general or special sense, or manifestations of the intellect. Nevertheless, a nerve fibre is affected by the passage along its course of the electric current. When the constant current of electricity is brought to bear upon a nerve, the whole nerve is brought to a condition of electric tension, the so-called electrotonus, during the existence of which, the sensitiveness of the nerve is very curiously changed. For in the part of the nerve near the positive pole the sensitiveness to irritation and the rate of conduction are markedly lessened, while in the part of the nerve near the negative pole the sensitiveness to irritation and the rate of conduction are as markedly increased. The condition of the nerve at the region of diminished sensitiveness is known as anelectrotonus, while the condition at the region of increased sensitiveness is known as catelectrotonus. These regions, however, are not confined to the intrapolar spaces, but extend on either side beyond the poles throughout the entire course of the nerve. Between the poles is a point where neither increase nor decrease may be observed and this point is known as the neutral point. Finally, the arrest or diminution of the natural electric current, caused by the passage of the natural nerve force, constitutes what is known as the negative variation of the electric current.

Nerve Force.

We are as ignorant of the ultimate changes in nerve cells, which attend the conversion of latent force in the blood into active nerve force, as of the ultimate changes which take place in any body, when it produces light, heat, electricity, or any physical force. We are forced to content ourselves, therefore, with the study of the properties and actions of nerve or other force. We recognise the fact that the influence of irritants or impressions are conducted along afferent nerve fibres to nerve cells, whence they are transmitted through efferent nerves to motor, glandular, etc., structures. Such a process constitutes a reflex action.

But the nerve cell has also the property of retaining the influence of the external impression, and releasing it at a later period. This later period may be very remote from that of the original impression. When the action then supervenes, it is known as a volitional act. Acts of volition therefore are, in reality, reflex actions, whose constituents are separated by longer intervals.

We do not, of course, look upon nerve force as a simple transfer of the external irritant. The nerve force is just as different from the external force, as muscular force is from nerve force. And just as a small amount of nerve force may call into action a large amount of muscular force, so a small amount of external force may evoke a large amount of nerve force. The nervous system is, thus, just as much a machine as is the muscular system, or the gland system. The nervous system is a machine for the transformation of outside force into nerve force. We can, therefore, no more conceive of force being developed spontaneously, or automatically, in the case of nerves, than in the case of muscles. What is true, thus, of the grosser phenomena of nerve tissue, sensation, motion, secretion, etc., must be true of the more intricate processes connected with the special senses, and the faculties of the mind. Impressions are made upon the nerve cells through the avenues of nerve fibres of general or special sense. These impressions may be reflected to act at once through motor nerves, or they may be stored up to constitute memory. We do not know what material changes occur in the nerve cells during the reception, reflection or retention of these impressions, any more than we know what changes take place in any protoplasm when it absorbs, assimilates, or excretes matter, or any more than we know what changes take place in an iron bar when it becomes magnetic. We appeal in our ignorance to molecular changes, but we do not accept them as positive facts until their character and degree shall have been definitely demonstrated.

What shall we say then of the higher actions of the nerve cells (cerebrum), which have come to be differentiated from the rest and set apart for purely intellectual purpose?

We observe, in the first place, that the development of these cells is a gradual process. The cerebrum is an addition to forms of life highest in the animal scale. Its cells are intimately linked with the cells of all other ganglionic masses lower in physiological dignity. We should therefore naturally infer that the same laws which apply to the nerve fibres and cells composing the spinal cord and sympathetic system would also apply to the nerve fibres and cells of the cerebrum. We observe, then, in the second place, that no intellectual phenomena of any kind are born with an individual of even the very highest form of life in the animal scale. All the movements and actions of the body are as distinctly reflex in the new born child as in the fœtus in utero. The cry, the seizure of the breast, the direction of the eyes towards a light, are all purely and simply reflex actions. The intellectual manifestations are in every case slowly, and we might almost say painfully, acquired. The capacity or aptitude for acquisition exists, it is true, because the character of the apparatus is rigidly determined by inheritance, but the acquisition itself is entirely a matter of education. A human being kept away from light, would not be able to see; kept from sound, it could not hear or speak; kept from the reception of ideas, it could not think. We find ourselves forced to the conclusion that the purely intellectual processes, as they are called, the memory, the reason, the will, result entirely from the impression of outside influences. Inheritance determines the aptitude or plasticity of the brain cells to impressions, and the character of the impressions determines the character of the mind. In other words:—

> "L'instruction fait tout; et les mains de nos pères
> Grave en nos faible cœurs ces premières charactères"
> Que l'example et le temps nous viennent retracer
> Et que peut-être en nous Dieu seul peut effacer." Voltaire.
>
> (Instruction does all; our father's hands
> Engrave in our hearts indelible bands,
> Which time and example only retrace
> And which God [death] alone may ever efface.)

Rate of Conduction.

Although we are ignorant of the ultimate essence of nerve force we are by no means entirely unacquainted with its properties and effects. We have in the first place some quite definite information as to the velocity or rapidity with which it travels. When this question first excited the attention of physiologists, it was considered a subject beyond the possibilities of human comprehension. Haller thought that it would be impossible to measure the rate of conduction of nerve force because there was not sufficient distance for estimate as in the case of light. But as Goethe has said "one must continue to believe the inconceivable to be conceivable, else there will be no discovery." Continued investigation has at last been rewarded with positive results so that we possess now tolerably accurate data regarding the velocity of nerve force. By attaching two levers to two different parts of a muscle and causing the muscle to contract by stimulating successively two different parts of the trunk of the nerve terminating in the muscle, Marey was able to determine that the response of the muscle was quicker to the irritation nearer the muscle. The interval which lapsed between response to stimulus at different points along the nerve corresponds to the rate of conduction between the points. The distance between these points being known, it is easy to estimate the rate of conduction along the entire nerve. In like manner, by noting the interval of time which lapses between perception of an irritation at a distant point, as at the foot, and at a near point, as on the face, the rate of conduction along sensitive nerves was approximately established. Though this rate of conduction differs in different animals, being more rapid in warm blooded animals; differs in the same animal at different degrees of temperature, being increased by heat and diminished by cold; differs also in the same nerve at different parts of it course, being increasing in motor nerves as the nerve approaches the periphery, and in sensitive nerve as it approaches the centre; differs, lastly, according to the degree of freshness or fatigue, being much slower in fatigue; the general velocity of conduction is estimated at about 100 feet per second. Auerbach and v. Kries have shown that the perception of the difference between two different impressions upon the sense of touch requires, as a rule, 0.021-0.036 of a second; of hearing 0.019-0.053 second, according to the quality of the tone; but the localisation of a noise required 0.032-0.077 second. The perception of the difference of two objects addressed to the sense of sight required 0.011-0.017 second. The recognition of the difference between two different colors (blue and red) required 0.012-0.034 second. In appeals to the sense of touch and taste in the tongue, Vintschgau and Hönigsmied found that touch was always experienced first. The perception of taste required for salt 0.05, for sugar 0.20, for quinine 0.49 second.

Nerve Force Analogous to, but not Identical with, Electricity.

Though electricity more closely than any other force resembles nerve force, their rates of travel alone afford positive evidence that nerve force is not electricity. For electricity travels at the rate of many thousand miles a second. While it is true that electricity is developed in nerves during rest of the nerve, as the result of the chemical operations in continuous operation, this electricity is at once arrested so soon as the chemical force may expend itself as nerve force. That is, the most delicate galvanometer fails to register in nerves the faintest electrical current during the transmission of nerve force. This fact is, of course, simply another illustration of the operation of the law of the conservation of force.

Comparative Velocity of Nerve and other Forms of Force.

Nerve force, thus, travels at about the rate of an express train. It is much more rapid than muscle force, but is infinitely more slow than light or electricity. We may form some more definite idea of the velocity of nerve force by a comparison with that of some more familiar forces. Le Bon presents us for this purpose the following table in which the figures represent so many metres (a metre is about 40 inches) per second:—

Muscular Contraction	1
Race Horse	26
Locomotive	27
Nerve Force	30
Eagle's Flight	35
Sound in Air	332
Cannon Ball	550
Earth's Revolution about the Sun	30,800
Light	300,000,000
Electricity	464,000,000

The Reception and Perception of Impressions.

We fail to appreciate the interval of time between the reception and perception of an impression simply because of the short distance to be traversed between the brain and the ends of the most distant nerves. In very large animals, that is, in animals with very long nerves, as in the whale, a harpoon, thrust into the body near the tail, is not felt for an entire second, and as an additional second must elapse before responding motor force can be sent down from the brain, the movement of the animal could not occur in less than two seconds. So, in the case of a tall man, a mosquito operating upon the foot, would have the one-sixth of a second to make its escape, ample time, as we have seen, for the quick movements of insect life. Mr. Flower has expressed the opinion that the large animals of the tertiary epoch were all slow of motion and stupid, in comparison with modern species, and this sluggishness and dulness finds explanation in the mere size of the animals and corresponding length of the nerves. So the proverbial obtuseness and imperturbability of giants stands in marked contrast to the acuteness and activity of small people. Ponies and terriers are much more active and vivacious than horses and mastiffs.

But we are not to forget that the character of the receiving and generating centres is also an important factor in this consideration. Thus children "lose the benefit of their small stature from want of command and correllation of their faculties," that is, from want of development of the nerve cells. Cold blooded feel much less acutely than warm blooded animals. In Chamber's Journal is the story of a shark caught with a line, the hook of which tore open the abdominal cavity, cut out the liver, and left the intestines hanging from the body. The sailors, in abhorrence, threw it into the sea, but it continued near the boat and shortly afterwards pursued and attempted to devour a mackerel. In one of the older numbers of The Clinic is a well authenticated statement to the same effect. A fish was caught in the eye by a hook, and the eye ball was torn from the socket. The eye ball was then left upon the hook as a bait, and in a little while it secured the rest of the animal in the usual way.

It is therefore not true that

> "The poor beetle that we tread upon
> In corporal sufferance finds a pang as great
> As when a giant dies."

though the pain experienced by the albatross, shot by the ancient mariner, may have been as keen as that felt by a human being. The sportsman, who so cruelly wounds birds and runs down mammals, inflicts far more torture than the physiologist with his experiments upon frogs, and has less justification for his work.

Ancient Significance of Nerves.

Nerves were not known as such by the older anatomists and physiologists. Hippocrates always confounded nerves and tendons. Hence the derivation of the word nerve (*νευρον*, cord). We speak yet of a strong nervous man, with reference to the original meaning of the term, and a weak nervous woman, with reference to its modern significance. Although the true nature of nerves was known to Erasistratus and Galen, we do not find any general recognition of it until almost within our own times. All the allusions of Shakespere concerning nerves, evidently refer to the sinews or tendons. Thus Macbeth cries out to the ghost:—

> "Take any shape but that, and my firm nerves
> Shall never tremble."

And Hamlet says, alluding to bloodvessels as cords:—

> "As hardy as the Némean lion's nerve."

The French translate the "sinews of war" literally, "*les nerfs de la guerre.*"

The Effects of Use and Disuse.

The literary allusions to the nervous system, therefore, still have reference to the mind and the mental faculties, chiefly from a metaphysical point of view, as sufficient time has scarcely yet elapsed for general appreciation of the physicial significance of nervous tissue. But there is one point connected with this tissue which has not, in its effects, at least, escaped general recognition. And that is, that the tone of the nervous tissue is only maintained and sustained by its exercise. If a nerve of whatever character be cut, and union of the divided ends be prevented, atrophy of the nerve inevitably ensues. The essential element of the nerve undergoes a granulo-fatty degeneration and at last entirely loses its capacity to conduct force. This atrophy then not only affects the nerve, but also the end apparatus of the nerve. The structure innervated dies with the nerve. Nor is the field of destruction limited to the nerve and its distribution; the nerve centres also suffer atrophy and finally cease to functionate at all. The same effect follows disuse of the centre, even though anatomical integrity of structure be preserved. The brain develops by use and atrophies by disuse. No sight is more melancholy than that gradual contraction of ideas, that irritability to trival cause, which inevitably supervenes in an active and liberal mind when its faculties cease to be exercised. Middle aged men who retire from active pursuits to secure the *otium cum dignitate*, secure the dignity perhaps, but generally lose the ease. Some allowance must, of course, be made for the defective nutrition of advancing age, but aside from this factor, or superadded to it, is the more marked desolation effected by atrophy from disuse. There are forms of animal life which in the earlier phases of existence are endowed with motion (cilia) and various organs of special sense. No sooner, however, do they become fixed in a convenient place than they lose their microscopic oars, lose. one after another, their special senses, become thus reduced to shapeless, inert, masses of protoplasm, and thus vegetate simply for the rest of their existence. Such reduction and waste occurs as the result of disuse throughout the animal scale.

We realise thus the force of Schiller's observation to Körner; "*Die Hauptsache ist der Fleisz; denn dieser giebt nicht nur die Mittel des Lebens, sondern er giebt ihm auch seinen alleinigen Werth.*" (The chief thing is industry; it not only furnishes the means of living, but also gives to life its sole worth).

The atrophic changes in the nervous tissue incident to age, make themselves manifest in the action of the nerve centres as well as in the loss of conductivity in the nerve fibres. The intellectual and moral faculties suffer the same alterations as the special senses. The organs of communication with the external world being blunted in their nice perceptions, the old man has only his memories whence to derive his intellectual food. As he cannot comprehend the world about him in its new order, he looks upon all that is new with distrust, if not absolute aversion. But this blunting of the sympathies enables age to regard events and occurrences dispassionately, and hence peculiar wisdom is ascribed to this period of life by all peoples and in all lands. "If we consider this epoch," remarks Carl Vogt, one of the most profound philosophers of his day, "in its retrocessions of the feelings, in its insensibility to external impressions, in its lack of the loftier inspirations, in its insipidity of intellectual productions, we may well cease to begrudge it, the wisdom usually ascribed to it."

At last, ensues the last stage of atrophy, and:—

> "From Marlborough's eyes the tears of dotage flow
> And Swift expires a driveler and a show."

LECTURE XII.

THE BLOOD AND ITS PROPERTIES.

CONTENTS.

The Value of the Blood—The Transfusion of Blood—The Constitution of the Blood—The Color of the Blood—Reaction of the Blood—The Odor of the Blood—The Taste of the Blood—The Temperature of the Blood—The Weight of the Blood—The Quantity of the Blood—The Morphology of the Blood—The Red Blood Corpuscles—Size of the Red Corpuscles—Number of the Red Corpuscles—Elasticity of the Red Corpuscle—Constitution of the Red Corpuscles—Use of the Red Corpuscles—The Colorless Blood Corpuscles—The Blood Plasma—The Coagulation of the Blood—The Blood as the Substitute of the Body.

The Value of the Blood.

The blood is for the most part, the prepared, digested, fluidified, food. But the blood is made up also of the waste products of the body. The blood thus officiates as the fresh food (solid, liquid, and gaseous) supply and at the same time, as the sewage escape. No where in art may we observe a nutrient supply conveyed along the same conduits or tubes with waste matter without suffering contamination. "The blood circulating through the body may be regarded as a river flowing by numerous canals through a populous city, which not only supplies the wants of the inhabitants, but conveys from them, all the impurities which through various channels find their way into its stream" (Bennet).

The mass of the blood is the digested food. To secure the elaboration of the coarse elements of the food into the finished elements of the blood, is the work of a digestive apparatus, which is extensive and complicated according to the nature of the food. For food is of no use to the body until it is converted into blood. It is the blood which is consumed in the processes of life; thus directly or indirectly, all animals are carnivorous.

The blood of plants is the sap which is made up of the fluidified salts of the earth. The material which acts as blood for the lowest forms of animal life is the sea or the water in which they live.

Blood (Saxon, blod), in some form or other, is thus the most important juice in the body, and its value was recognised long before its nature and character were established. We observe something of the popular recognition of its significance in the aversion, or feeling of horror, which the mere sight of it occasions. The shedding of blood is associated with the loss of life. So blood is the fluid, so to speak, with which tragic artists paint. Helena, when she finds Lysander asleep (Midsummer Nights Dream), can not believe him hurt, because as she says:—

> "I see no blood, no wound!"

And the watchman in the grave yard scene (Romeo and Juliet) appreciates the injury to life with the exclamation and injunction:—

> "The ground is bloody; search about the church yard:
> Go, some of you, whoe'er you find, attach."

The Transfusion of Blood.

Perhaps no single experiment so convincingly exhibits the fact that "the blood is the life" as the practice of injecting fresh healthy blood into the veins of an animal dying from its loss. Almost simultaneously with the reception of the blood, the respiration becomes more profound, the pulse becomes again perceptible, consciousness returns with motion and sensation, in short, the animal is restored to life.

The operation of transfusion of blood was first practised on man by a French physician, Denis, June 15, 1667, with defibrinated blood from a calf, though numerous experiments had been previously made upon lower animals. The first recorded intimation of the operation is found in Ovid's Metamorphoses, book vii, fable ii, in the order of Medea to the daughters of Pelos: "unsheath your swords, and exhaust the ancient gore, that I may replenish his empty veins with youthful blood." But this statement is usually construed by commentators to have only metaphorical meaning, and to have reference to the vivifying effect of a potent decoction which Medea had previously used on animals and men. However this may be, it is known that the modern operation of transfusion was largely discussed by the metaphysicians of the middle ages, that period so replete with curious and fantastic projects, and was even practised to some extent upon lower animals. As a sample of the fabulous expectations entertained of transfusion, at this time, I may mention that it was generally believed that the long sought secret of rejuvenation had been at last discovered. Very soon after the first practice of the operation upon man, marvelous results began to be reported. Cases of insanity were cured, lost special senses were restored, and aged and decrepit constitutions rehabilitated with the vigor of youth. Time, the *experimentum crucis* of all discoveries, soon dissipated all these conceits, and the number of accidents and fatal results which attended the operation at last brought it into disrepute, when legal injunction caused the practice of it to be suspended and forgotten. In this oblivion it laid, then, until the beginning of our own century, when it was revived by a distinguished obstetrician of Dublin, Blundell (1818), with such improvements in method and restriction in practice, as to give it permanent place among the most valuable acquisitions to modern therapy.

In our day, transfusion is limited to cases of hemorrhage, where it is peculiarly adapted to meet the indications, and to cases of poisoning by toxic agents (sewer gases, for instance) for which we have no antidote. A temporary renewal or protraction of life may also be effected with it in cases of phthisis, and sometimes permanent relief afforded in cases of inanition from any cause, when the ordinary avenues of food are temporarily blocked, or may not be addressed, as in cases of gastric ulcer. It is highly probable, however, that other nutrient fluids, an artificial serum, or milk, will gradually substitute blood in the majority of cases.

Though the transfusion of a few ounces of blood usually suffice, according to the observations of J. Worm Müller, rabbits and dogs may receive as much as eighty per cent. additional blood without permanent injury. Inexplicable laws regulate the kind of blood which an animal may receive. The transfusion of the blood of birds into the veins of mammals produces convulsions and death, as does also the transfusion of some mammals blood into the veins of other mammals. Dogs blood may be injected into the veins of rabbits with perfect impunity, while sheeps blood rapidly proves fatal (Mittler).

Most remarkable results have been obtained by the injection of blood into the veins of animals recently dead. Brown-Séquard has performed a great many experiments of this kind, and his accounts of effects secured would seem incredible, were they not in full accord with our knowledge of the part the blood plays in the animal economy. On one occasion, he decapitated a dog, taking care to make the section below the point where the vertebral arteries penetrate their osseous canals. "Ten minutes after cessation of the respiratory movements of the nares, lips and lower jaw, I inserted into the three arteries of the head canulæ connected by caoutchouc tubes to a copper cylinder containing oxygenated blood. The blood was now injected by means of a syringe. In two or three minutes, the eyes began to move, as also the muscles of the face, and these movements seemed directed by the will. I prolonged this experiment a quarter of an hour, and during all this time, these movements, apparently voluntary, continued to take place. When I ceased the injections, the movements ceased and were soon replaced by convulsive movements of the eyes, face, respiratory movements of the nose, lips and jaws, and finally by the tremors of the death agony. The pupils now dilated and became fixed as in ordinary death." On a subsequent occasion, the same experimenter injected into the veins of a dog, just dead from peritonitis, some fresh blood from a living dog, and the dead dog so far revived, as to stand upon his feet, wag his tail, make various voluntary movements, and survive for twelve and a half hours, when he again laid down, and died the second time. No physiologist has, as yet, had the temerity to practice this operation upon the brain, or the whole body, of a human being, not even for juridical purposes, where it might seem justifiable, but there can, of course, be no doubt as to its result. Prof. Vulpian remarks upon this subject:—"If a savant should attempt this experiment upon the head of an individual who had been decapitated, he would assist in the production of a grand and terrible spectacle; he would re-awaken in the head all its cerebral functions; he would restore, in the eyes and facial muscles, the movements, which in man are evoked by the emotions, and the thoughts, of which the brain is the seat."

Constitution of the Blood.

The blood consists of a fluid, the so-called plasma (Schultze), and of formed elements suspended in the fluid, the so-called blood corpuscles (Müller). The only exception to this constitution of blood is offered by certain worms, the nemertinea, in whose blood no corpuscles have as yet been discovered.

The Color of the Blood.

The blood of all vertebrate animals, with the single exception of the lowest of all, the lancelet, is red. The blood of invertebrate animals is either colorless, or is of other color than red, as blue, yellow, green, brown, etc. When the blood of invertebrate animals is colored, it is the plasma which contain the coloring matter, whereas, in vertebrate animals, the corpuscles contain the coloring matter, and the plasma is colorless, except in cephalopods, where the corpuscles have a violet hue, and the terebella, whose corpuscles are yellowish-red (Gscheidlen).

But the red blood of vertebrate animals varies in its tint. Like all other colored fluids (sea-water, for instance), the blood is darker when present in quantity. A thin layer of blood or a single corpuscle presents a faint amber hue, which may be regarded as the intrinsic color of blood. The freshly oxygenated blood as it leaves the lungs and heart to circulate throughout the body in the arteries is a bright scarlet red. The deoxygenated and carbonised blood as it collects in the veins to be returned to the heart and lungs is purple or blue. The intrinsic color of blood is due to the presence in the corpuscles, as one of the ingredients of construction, of hæmoglobin, which, as its name implies, contains iron. The degree in which the iron is oxydised determines the tint of the blood. Thus the coloring matter of the blood is iron, a fact which gave to Mr. Ruskin the opportunity for a bit of sentiment in the comment that it seems strange that iron, one of the sternest and hardest substances in nature, should be selected to give expression in the face to the most delicate emotions of the heart.

> "Behold how like a maid she blushes here:
> Comes not that blood, as modest evidence
> To witness simple virtue?"

Reaction of the Blood.

The blood of all animals is alkaline. We have already seen how this alkalinity of the blood favors oxidation processes, and the importance of this reaction becomes evident with the statement that so soon as the alkalinity of the blood of an animal is neutralised, by the injection of an acid into the vessels, the animal inevitably dies. But it is only fresh and living blood that exhibits alkalescense. Dissolved, dried blood is mostly acid and the alkalescence of fresh blood continues to diminish after withdrawal from the body. Thus 40 cubic centimetres of phosphoric acid are required to neutralise 100 cubic centimetres of blood freshly drawn, while 31 centimetres suffice to neutralise blood which has been drawn five minutes. It is by reason of the alkalinity of the blood which is chiefly effected in man by the phosphate of soda entering into its composition, that the fluidity of the blood is preserved. Blood withdrawn from the body is kept fluid by the addition of alkalies, as of ammonia or the sulphate of soda.

The Odor of the Blood.

The blood has a peculiar odor, which is different in different animals. Thus oxen blood smells of musk, and the blood of many insects (caterpillars) has an exceedingly disagreeable odor. In fact, it is the blood which largely gives the characteristic odor to the animal. The odor of the blood is due to the existence in it of certain volatile fatty acids, in alkaline combinations, whose quantity and exact nature is as yet undetermined. Concentrated sulphuric acid liberates the characteristic odor of the blood in much greater intensity, or develops it when not present in sufficient degree to be perceptible (Barruel), and valuable juridical evidence has been furnished in this way in doubtful cases. This *halitus sanguinis* of the older physiologists is somewhat more marked in male animals. To obtain or develop the odor of the blood in any intensity, it should be received from a vein in a glass vessel and concentrated sulphuric acid should be added to it, in the proportion of one-third to one half the quantity of blood. The odor of cattle, sheep, dogs or fishes may be distinctly recognised in this way.

The odor of fresh human blood is not very distinct at best. It was a psychical conception and not a physical impression which Lady Macbeth perceived with such intensity, when in her somnambulism she muttered:—

> "Here's the smell of the blood still: all
> the perfumes in Arabia will not sweeten
> this little hand."

The Taste of the Blood,

though not so distinctly characteristic of its source, is nevertheless peculiar. The taste of the salty, sweet, and extractive elements so mask each other as to render the gustative impression of the blood *sui generis.*

The Temperature of the Blood.

The blood is kept in the body at a temperature of about 100° F. (38°C.) But much variation in temperature is encountered in different vessels. The blood of the surface capillaries, being cooled by exposure, may fall, even a degree or two, according to the external temperature, while in the interior of the body, it may be elevated six or seven degrees. As all chemical action develops heat, we might naturally infer, what direct observation positively confirms, that the blood is warmest in places where chemical processes are most active. So the very hottest blood in the body is found in the hepatic veins, vessels which receive the blood after the intensely active chemical processes of the liver. The temperature of the blood here mounts up to 107° F. (41.6° C.), a degree which if maintained for a length of time upon the surface of the body would indicate inevitably fatal oxidation. But the general heat of the blood and of the body is almost exclusively sustained by the oxidation processes effected by muscular tissue. Donyza's servant then gives his mistress proper counsel in the advice:—

> "Pray you walk softly, do not heat your blood."

The Weight of the Blood.

The specific gravity of the blood varies between 1054 and 1060. To obtain it, the blood must of course be thoroughly defibrinated. This is accomplished by flagellation of the blood with a wisp of straw, or by stirring it with a spatula or glass rod. The specific gravity of the plasma is 1028, and of the corpuscles 1088. The corpuscles being thus much the heavier, sink in the plasma whenever the blood comes to rest. The red corpuscles being heavier than the white sink faster, and leave the white to form the "buffy coat" on the surface of the clot. The buffy coat is thus no sign of inflammation (crusta inflammatoria) as formerly believed. It simply indicates in its depth the sluggishness of coagulation. It is always seen in the blood of the horse withdrawn from the body of the animal. The specific gravity of the blood is markedly decreased by hemorrhage and increased by transfusion.

The Quantity of Blood.

It would seem to be an easy matter to arrive at the whole quantity of blood in the body of an animal by simply opening large vessels and collecting it as it flows. But the blood will not all flow out from the body. When syncope supervenes, the blood ceases to flow in quantity from paralysis of the vaso-motor nerves, and no posture can be secured which will permit gravity to effect the discharge of blood from all the vessels.

A more effective method is to collect all the blood that will flow spontaneously, and then wash out the rest by injection with a known quantity of water, which could be subtracted from the whole amount. The objection to this method lies in the fact that a forcible injection would carry out other fluids, lymph, chyle, muscular fluids, synovial serum, etc., which would pass into the bloodvessels by diffusion and thus invalidate conclusions.

Some idea of the difficulties encountered in computing the whole amount of blood may be gathered from the different estimates obtained by different experimenters. Thus Harvey, Lister, and Moulins compute that the human body contains about 8 lbs. of blood, Müller and Burdach 20 lbs., Haller 28–30 lbs., Hamberger 80 lbs., and Keill 100 lbs., differences which sufficiently exhibit the defectiveness of the methods employed. From among the many improved methods of more modern investigators, I may mention that of Lehmann and Weber which consisted in collecting all the blood which would flow spontaneously from the divided vessels of decapitated animals, washing out the vessels until the water injected escaped colorless, and then evaporating the fluid to a solid residue which represented, of course, a certain amount of blood. In this way these observers estimated that the proportion of blood to the body was about that of one to eight; that is, the body of a man of average weight, 145 lbs., contains about 18 lbs. of blood, a quantity too great because of admixture with other fluids.

Vierordt made a computation by multiplying the quantity of blood expelled from the heart at each ventricular contraction by the number of beats required to effect the entire round of the circulation. If the ventricle pump out 6.3 oz. (an amount evidently too great), and 27.7 contractions are necessary to effect the round of the circulation, as he maintains, the proportion of blood to the body would be $\frac{1}{12}$–$\frac{1}{13}$, about 11–12 lbs. Welcker first employed the color test, which consists in mincing the body of the animal after all its blood has escaped, and been washed out. The mince meat was then infused and the color of the infusion compared with that of previously prepared color tests containing a known quantity of blood. Welcker concluded that the body of a man (143 lbs.) contains about 11 lbs. of blood. Preyer's spectroscopic test (estimation of the amount of hæmoglobin) yields about the same result, as does also the entirely different method of Brozeit, which consisted in the recovery of the haematin from the washed out blood, so that this proportion, the $\frac{1}{13}$, may be assumed to represent the amount of blood in the body. The proportion of blood to the rest of the body in different animals is about as follows: guinea pig, $\frac{1}{17}$–$\frac{1}{22}$, rabbit $\frac{1}{15}$–$\frac{1}{20}$, dog $\frac{1}{12}$–$\frac{1}{18}$, cat $\frac{1}{15}$, birds $\frac{1}{10}$–$\frac{1}{13}$, frogs $\frac{1}{15}$–$\frac{1}{20}$, fishes $\frac{1}{14}$–$\frac{1}{19}$.

It must not be forgotten, of course, that the quantity of blood varies very greatly at different times of the day, with reference especially to the hours of taking food. Bernard illustrated this fact by drawing ten and a half ounces of blood from a rabbit, after eating, without serious result to the life of the animal, whereas the withdrawal of five ounces proved fatal to the animal fasting. According to Colard de Martigny, the quantity of blood in a rabbit, in a healthy well-fed state, is about 30 grammes, which is reduced by three days fasting to 20 grammes, and by ten days fasting to only 7 grammes. This great variation with reference to meals may account, as Carpenter suggests, for the wide discrepancies observable in different estimates of the whole quantity of blood. Then the average quantity is widely departed from in cases of plethora and anæmia. Thus Wrisberg states that a plethoric woman, who died of metrorhagia, lost 26 lbs. of blood, and reports the fact that as much as 24 lbs. was collected from the vessels of a woman who had suffered death by decapitation.

The Morphology of the Blood.

The blood as it flows from a divided vessel is apparently a perfectly homogeneous fluid. But on examination under the microscope it is seen to contain, in myriad numbers, certain formed elements, the corpuscles. The corpuscles seem to occupy about half the space in the microscopic field. It was not given to Harvey, the discoverer of the circulation of the blood, to ever see the blood corpuscles or the capillaries in which their course and conduct in life are distinctly visible. The blood corpuscles were first recognised by Malpighi (1661), as peculiar and hitherto unrecognised particles, floating in the current of the blood. Malpighi, however, did not appreciate their significance; he regarded them as particles of fat. It was only then after the lapse of twelve years, that Leeuwenhoek was able to describe the true nature of the red corpuscles, as morphotic elements, always present in the blood. And it was not until a hundred years later still, that the second variety of bodies, the white corpuscles, were pointed out by a distinguished English observer, Wm. Hewson. The recognition of the morphotic elements of the blood, was then only finally complete with the discovery by Schultze (1865) of certain, minute, irregular, colorless, granules, distinguished by their varying quantity and their great refrangibility. As we have as yet no knowledge of these bodies, other than that of their existence, we may pass to the consideration of the elements with whose nature and use we are most familiar.

The Red Blood Corpuscles.

There is a description of the red blood corpuscle that is so concise and complete as to have been adopted in most works on physiology. The blood corpuscles are described viz., as "flattened, biconcave, circular disks." So, then, we may say, roughly, that red blood corpuscles look like biconcave lenses, or like crackers (butter crackers), without their central elevation. The camel and the lama are the only mammals whose corpuscles depart from this shape, in that in these animals, the red corpuscles, like those of fishes, amphibious animals, reptiles, and birds are elliptical. The exceptional shape of the corpuscles in the camel species is very remarkable, in that the small family of the camelidæ is thus distinguished alone among all mammals. Milne Edwards sought for elliptical corpuscles in more than 200 species selected from all the natural subdivisions of this group, but could not find them "even among the marsupials and monotremata, which seem, in certain respects, to establish a transition between ordinary mammals and oviparous vertebrates." The elliptical shape of the blood corpuscles of the camel tribe, like the existence in the small intestine, of the same tribe, of valvulæ conniventes, which were once believed to be characteristic of man, is, when properly interpreted, additional evidence of the mutability of species.

In the study of the structure and properties of red blood corpuscles, the precaution must always be taken to add to the specimen of blood some diluent. Else, the corpuscles speedily shrink from evaporation of their fluid contents, become crenated upon their edges, and finally shrivel away. But the character of the diluent must be selected with caution. The addition of simple water dissipates the corpuscles from the field in a very few minutes. The water is very quickly absorbed, the coloring matter is separated, the corpuscles swell to colorless spheres, burst, or are entirely dissolved from vision. The best fluid in which to preserve corpuscles is the natural serum of the blood, and the serum should be taken from the same animal or from the same species of animal. For, according to Landois, the blood corpuscles of the rabbit, for instance, are transformed, on the addition of the serum from dogs blood, to spheres or balls, and the coloring matter is dissolved out. In the absence of serum, a six per cent. solution of common salt exercises the least injurious effect upon the size, shape, and structure of the corpuscles. Blood corpuscles (of any animal) are best preserved by holding a thin layer of blood over an aqueous solution of perosmic acid, in such a way that its vapor may pass to the blood. The blood corpuscles are hardened in this way, without change of form or color. They maintain also their central depression and become so consistent that they may be kept unaltered for a very long time in water or in glycerine. It is the central depression which gives to red corpuscles their peculiar optical appearance. Either the centre is dark and the circumference light, or vice versa, according as one or other is in focus.

Size of the Blood Corpuscles.

By means of a micrometer it is not difficult to measure the exact size of the blood corpuscles of an animal, a point of great medico-legal interest. Yet there is by no means that unaminity of statement upon this subject that might naturally be expected. Thus Kölliker, the highest German authority says, as regards human corpuscles, that 95 out of every 100 corpuscles measure $\frac{1}{3600}$ of an inch (0.0071 mm.) in diameter; Robin, the highest French authority states the exact diameter to be $\frac{1}{3437}$ of an inch (0.0073 mm.); while

Gulliver, who examined the corpuscles of all the animals in the London Zoological Garden, and hence had great experience in measurements, puts the diameter of human corpuscles at $\frac{1}{3200}$ of an inch, a fraction which is undoubtedly too high.

That there is no relation whatever, between the size of an animal and the size of its blood corpuscles is evidenced by reference to Gulliver's table, showing the size of the corpuscles in 176 mammals. The ox, for example, a very large animal, has a blood corpuscle whose diameter is exceedingly small, $\frac{1}{4267}$ of an inch, much smaller, thus, than that of the corpuscles of man; while the cat, a small animal, has a corpuscle $\frac{1}{4404}$ of an inch diameter, very nearly as large as that of the ox, and the mouse, which is much smaller than the cat, has a much larger corpuscle, viz., $\frac{1}{3814}$ of an inch diameter, much larger, thus, than that of the ox.

Milne Edwards has endeavored to show that there is an inverse relation between the size of the corpuscle and the muscular activity of the animal, that is, the more active animals have the smallest corpuscles. There is much foundation for this observation, which may, indeed, be considered a rule, but it is a rule, not without exceptions. Thus the dog, a very active animal, has a corpuscle which is generally regarded as having exactly the dimensions of the human corpuscle, viz., $\frac{1}{3500}$ of an inch, while the ox, a very sluggish animal, has a much smaller corpuscle, $\frac{1}{4200}$ of an inch. As the size and shape of blood corpuscles are among the chief factors in the identification of blood, and its source, it is important to have definite and accurate data concerning every point. The differentiation of human blood from that of fishes, reptiles and birds, never offers the least difficulty, because of the elliptical shape of their corpuscles. They are not only ellipses, whose long diameter is about twice as great as the broad diameter, but they are also distinctly embossed (biconvex). But the differentiation of human blood from that of lower mammals is effected with great difficulty and in some cases can not be effected at all.

The most recent and reliable measurements of blood corpuscles have been furnished by Welcker, who estimated the size of his own blood corpuscles from 130 observations as follows:—

Greatest transverse diameter	0.00774 mm.
" thickness	0.00190 "

These measurements were made by introducing into the eye-piece of a microscope, a micrometer, whose lines stood, under a magnification of 620 diameters, 0.001723 mm. apart, and the tenths of a division could be estimated with accuracy. The blood corpuscles were suspended in serum, and evaporation, as well as agitation, was prevented by fastening down the edges of the cover glass with Canada balsam (Gscheidlen).

Welcker also made measurements in the case of other animals as follows:—

Animals.	No. of Observations.	Average Diameter.
Elephant	20	0.0094 mm.
Dog	10	0.0073 "
Rabbit	20	0.0069 "
Cat	20	0.0065 "
Sheep	20	0.0050 "
Goat	20	0.0041 "
Deer	5	0.0025 "

And of animals having elliptical corpuscles as follows:—

Animals.	No. Obs.	Long Diameter.	Short Diameter.
Lama	20	0.0080	0.0040 mm.
Pigeon	20	0.0147	0.0065 "
Frog	50	0.0223	0.0157 "
Triton	20	0.0293	0.0195 "

The Number of Red Corpuscles.

The number of blood corpuscles in a given quantity of blood may be ascertained by directly counting them in a known quantity under the microscope, and multiplying this known quantity, a fractional part of a drop, by the whole quantity under consideration. A better method, however, is to dilute a known quantity of blood with a known quantity of serum or salt solution, and then count and compute as before. From these methods it is estimated that a cubic centimetre of human blood contains 4,231,500 (Stöltzing), 4,620,000 (Welcker), 5,174,000 (Vierordt), corpuscles. In anæmia, leucocythæmia, etc., this number may be reduced by millions, to be again restored by chalybeate, or other suitable treatment. The whole number of corpuscles in the blood of a man of average weight is roughly estimated at about twenty-five billions.

Elasticity of the Red Corpuscle.

The red blood corpuscles are highly elastic bodies. When studied under the microscope it is observed that pressure of the cover upon the object glass flattens them, but they speedily recover their original shape and size when the pressure is relieved. Observed in the capillary vessels (web of frog's foot, tail of lizard, mesentery of mouse, or lung of frog) they are seen to become elongated almost to a thread, and thus succeed in traversing capillaries whose diameter is much less than their own, to resume their original size and shape on escape into wider tubes. So they are sometimes caught at an angle, formed by the division of one capillary into two, and to be swung first partly into one tube, then partly into another, changing their shape (passively) continually, until, finally, sufficient *vis a tergo* from the proper direction sweeps them entirely into one or other tube. The elasticity of the corpuscle is also manifest in the constant change of shape they are made to undergo under permeation and surrender of various gases. Carbonic acid gas distends the corpuscle, and oxygen leaves them more flat, a factor which partially effects the difference of color between arterial and venous blood. The red corpuscles, therefore, are rather semi-fluid than semi-solid. They are to be regarded as thoroughly homogenous bodies, like particles of jelly and are in no sense cells, in the ordinary acceptation of the term, with walls, contents and nuclei.

Constitution of the Corpuscles.

The red blood corpuscles are composed of a gelatinous basis; the stroma, and the iron containing, albumenoid, coloring matter; the hæmoglobin. The hæmoglobin is easily soluble in water or serum but is so intimately blended with the stroma, as to require artificial intervention to effect its separation. If blood be repeatedly frozen and thawed, or if successive strokes of electricity be transmitted through its mass, the hæmoglobin is separated, and is held in solution by the plasma, so that the blood loses its opacity (which is due to the different angles at which the corpuscles and the plasma refract light) and becomes quite translucent like colored varnish. Dilution with water, the addition of bile salts, agitation with ether, chloroform, alcohol or bisulphide of carbon effect the same result (Fick). So also septic and miasmatic germs, in disorganising the corpuscles, liberate the coloring matter, so that the skin, mucous membranes, in fact, all the tissues, become stained with it. This constitutes the hematogenous icterus of yellow, malarial, typhus, etc., fevers. The hæmoglobin when thus separated assumes special rhombic forms which may be differentiated from the forms assumed by the hæmoglobin of lower animals.

One of the most reliable of all the tests for blood is the spectroscopic test afforded by the lines formed in the spectrum by hæmoglobin, when oxidised (oxyhæmoglobin), as in arterial blood, or when reduced, as in venous blood. Reduced hæmoglobin distinguishes itself by an absorption band in the yellow part of the spectrum. If now this solution of reduced hæmoglobin be agitated with oxygen, the absorption band falls into two, one of which approaches the line D, the other the line E of the solar spectrum, and the space formerly occupied by the absorption band of the reduced hæmoglobin is now clear. Hæmoglobin on standing for any length of time separates into an albumenoid substance and the iron coloring matter hæmatin. The addition of acids effects the same division. Hæmatin, dissolved in ether or in alkalies, or reduced, gives also special bands in the spectrum.

The stroma of the corpuscles is a very complicated combination of an albumenoid substance (protagon or lecithin) with salts of potash and phosphorus and with fats and cholesterine. It is markedly hygroscopic, swells by imbibition with water, and thus restores the size and shape of blood corpuscles after the dessication of years. Blood stains, shaved up from floors or scraped from knives, have been recognised as such, by this restoration of the size and shape of dried corpuscles, after the lapse of several years.

Use of the Red Blood Corpuscles.

The red blood corpuscles are the oxygen carriers to the tissues. They arrive at the lungs partly emptied of oxygen, receive an additional quantity as the result of inspiration, and are swept off into the general circulation by the action of the heart. In the capillaries, the oxygen, a great part of it, at least, is surrendered to the tissues, and carbonic acid gas is received in its place. The blood corpuscles have the property of absorbing ten to thirteen times as much oxygen as water. The blood plasma will absorb two or three times as much oxygen as water, and this constituent officiates in its conduction, though to much less degree than in the conduction of carbonic acid gas.

The red corpuscles being thus so distinctly the oxygen carriers, any marked diminution in their amount should produce symptoms of asphyxia. And, in fact, it is observed that animals dying of hemorrhage experience first vertigo and syncope, from lack of oxygen for nervous supply, become finally convulsed, and die panting for air. So Paul Bert has shown that the resistance to asphyxia manifested by diving animals, so long inexplicable, is due to the simple fact that these animals have more blood, and consequently more blood corpuscles. Thus a chicken can be drowned or strangled in two minutes, while a duck of the same weight will survive seven or eight minutes. The duck has, however, one-third or one-half more blood than the chicken, and each additional corpuscle is, of course, an additional reservoir of oxygen gas.

The Colorless Blood Corpuscles.

Colorless corpuscles exist in the blood of both vertebrate and invertebrate animals. The first noticeable fact concerning the white corpuscles in the blood of man is their comparative paucity. They exist in the proportion of one to three to four hundred of the red corpuscles, but their absolute and relative number varies greatly according to the period of observation. That is, they are very markedly increased after meals. Thus Hirt found them present before breakfast, at the period of greatest fasting, in the proportion of 1:1800, after breakfast 1:700, before dinner 1:1500, after dinner 1:400, etc.

The white blood corpuscle differs from the red in other respects than color. In the first place it is larger than the red. Though Schultze describes three different sizes of white corpuscles, that which exists in greatest number and which is mostly studied, measures $\frac{1}{2500}$ of an inch (0.0101 mm.) in diameter. Secondly, the white blood corpuscle is not a disk. It is spherical in shape. It differs additionally in being abundantly granulated, and in containing a distinct nucleus.

Bodies which have always been regarded as similar, and which are now known to be identical in every respect to white corpuscles, are found also in the lymph and chyle, in colostrum, semen and in the vitreous humor of the eyeball. Such bodies constitute the morphotic elements of pus, where they are known as pus cells.

But what especially distinguishes white blood corpuscles (leucocytes), is their property of motion. They move like the amœbæ, which we have already studied, and hence are often known as the amœboid cells. Circulating in the vessels, they keep close to the wall of the vessel, while the red corpuscles form an axial mass in quicker motion.

This amœboid motion of the white corpuscles may be very easily brought under observation. A watch glass is filled with frogs blood, which is allowed to coagulate. The coagulum is then separated with a needle from the edge of the glass, and when a little serum has exuded, a drop of it is let fall upon a cover glass, which is then placed upon an object glass, so arranged that it can be kept warm. The edge of the object glass should be covered with oil, to prevent evaporation. The object glass is now to be gently heated. So soon as the temperature rises to 36° C. (96° F.) the well known processes of motion ensue. The movements of the white corpuscles of human blood, and their response to various stimulants, may be studied in the same way. The white blood corpuscles represent the incunabular stages of the red corpuscles, as transition forms have been discovered in abundance in the lymph glands, in the spleen, thymus and thyroid glands, supra-renal capsules, marrow of bones, etc., structures, all of them, found only in vertebrate animals, in which alone red corpuscles are found.

The Blood Plasma.

The plasma contains all the remaining ingredients of the blood except the corpuscles. To obtain a satisfactory analysis of the plasma it is necessary to examine the blood before coagulation and after the sinking of the corpuscles. As the corpuscles sink very rapidly in the blood of the horse, leaving a supernatural clear plasma, the most reliable results have been obtained from this animal. The following table exhibits the composition of the blood of the horse:

1000 Parts Blood Cont'n	Corpuscles 324.2	Water		184.30
		Solids 141.9	Hæmoglobin	122.75
			Albumen	17.80
			Lecithin	0.84
			Cholesterin	0.51
	Plasma 673.8	Water		579.4
		Solids 58.4	Fibrin	6.4
			Albumen	43.1
			Fat	0.8
			Extracts	2.5
			Soluble Salts	4.1
			Insoluble Salts	1.1

No fluid in the body has been subjected to so many and such careful and skilful analyses as the blood, but the conclusions reached by different observers have shown very marked differences. When we recall, however, what changes the blood must undergo, not only daily, and hourly, but in every second of time, in yielding up constituents for continuous supply, and in receiving as continuously the products of combustion and waste, we cease to wonder at any quantitative or qualitative discrepancies in the results of chemical analyses.

> "Nor are, although the river keep the name
> Yesterday's waters and to-day's the same."

The blood in its entirety contains, thus, proximate principles of the three different classes; of the inorganic class in its water, iron and salts, of the non-nitrogenous class in its fat, extractives and part of the lecithin, and of the nitrogenised class in its albumen, globulin and fibrin. Hence it is that the blood is the pabulum of all the tissues. It contains the materials out of which the protoplasm of all the tissues may evolve work, that is fuel, and it contains materials from which the tissues may repair their own waste. But all these matters do not really exist in the blood as such, and hence are not, strictly speaking, proximate principles. This is notably the case with regard to fibrin. Fibrin does not exist in the blood as such, and only presents itself as an ingredient when physiological conditions are in some way disturbed. Fibrin is a product of two substances, the so-called fibrin generators, paraglobulin and fibrinogen (A. Schmidt). Both these substances exist as such in the blood, and may be recovered from it by suitable manipulation. Nor is the albumen in the blood the same as ordinary albumen (white of egg). It differs from it in many chemical reactions, and more especially in its osmotic properties. If ordinary albumen be injected into the blood, it is not absorbed, but is rejected by the kidneys, while blood albumen is retained and absorbed.

The Coagulation of the Blood.

Within five minutes after blood is withdrawn from the body it begins to clot. A gelatinous pellicle first forms upon its surface and afterwards extends down the sides of the vessel containing the blood. When the vessel is now agitated, the mass of blood does not spill out; it quivers like a mass of jelly. Gradually now the process of coagulation invades the whole mass of the blood until, finally, the entire quantity has become "set." The time occupied in this solidification of the whole mass is, according to Nasse, from seven to sixteen minutes. The clot next begins to contract, and pellucid drops of fluid exude from its surface. The further process of coagulation consists in the continuation of contraction of the coagulum and expression of fluid until, in from 10–12 hours, the whole mass of the blood has become separated into "a clot" and surrounding "serum." The clot is composed of the fibrin, entangling the corpuscles, and the serum contains the water, the albumen and the salts.

The coagulation of the blood depends upon the fact that the fibrin generators, when placed under abnormal conditions, pass from the fluid to the solid state, that is, that the fibrin generators unite to generate fibrin. If a drop of blood be observed under the microscope, this gradual development of fibrin manifests itself in the formation of threads or fibrillæ, which extend across the microscopic field, entangling the corpuscles, which have now become packed up against each other, in rows or rouleaux, like coins upon a banker's table. The corpuscles escape entanglement if time be allowed for their subsidence. Thus when the blood coagulates slowly, naturally, or artificially (as by the addition of alkalies), the corpuscles gravitate to the bottom of the vessel. The position of the body at death, after subsequent change, has sometimes been determined by the location of the corpuscles in the clot, as in the longitudinal sinus. We have as yet no satisfactory explanation of the cause of the coagulation of the blood. None the less, however, are we able to appreciate its utility. Were it not for this formation of fibrin under certain conditions, to officiate as a plug for divided vessels, the slightest solution of continuity in the walls of a bloodvessel would be attended with fatal hemorrhage. In fact there are cases characterised by a deficiency in its formation, the so-called cases of hemorrhagic diathesis in which the extraction of a tooth, the scratch of a pin, the slightest lesions, permit the most disastrous hemorrhage. In these, cases, pressure or ligation of vessels, if of sufficient size, affords only temporary relief. When the pressure is relieved, or the ligature comes away, the hemorrhage, of course, recurs. Ordinarily, however, the coagulating blood blocks the orifice in the wounded vessel, and thus checks further loss. The great vessels in the walls of the uterus, after the extensive lacerations of parturition, are stuffed by clots of blood and, further escape is thus, as a rule, prevented. Thus, also, successive layers of fibrin are sometimes deposited in the walls of a vessel, weakened and distended by disease (aneurism), so that the weakest places become the strongest by this adventitious padding. Unfortunately, fibrin sometimes exercises a more malign influence, in being swept off in the torrent of the circulation, from surfaces upon which it has become deposited, to distant places, to block up most important vessels. Masses of fibrin (emboli) are thus occasionally detached from valves of the heart, upon which they have come to be deposited, in consequence of the roughening induced by endocardial inflammations, and carried to plug the great vessels feeding the brain, and thus cause the most serious lesions, and often death.

Here, then, we must conclude our brief survey of the properties of the blood. And whether we look upon it in the light of its mere complexity of construction, of the grave symptoms induced by even its partial loss, of its speedy reproduction after hemorrhage, of its maintenance of itself under the constant consumption which it must suffer, we can not fail to appreciate its importance. Magendie says that a celebrated physiologist became so convinced of the value of the blood as to define life as "the contact of arterial blood with the organs of the body, especially with the brain." If he had said, the consumption of the blood by the organs, and liberation of its latent force, he would have told all the truth. The older physiologists were fond of locating life as a peculiar principle or essence in the blood. It lodged in the pure or arterial blood. It was the promulgation of this delusion, that the soul dwelt in the arterial blood, that cost Servetus his life. Such temerity as the attempt to localise the soul awakened the ire of the theologians, and at the instigation and by the order of John Calvin, Servetus was publicly burned at the stake in Geneva, and nearly every copy of his works was thrown into the flames.

The older clinicians waged bitter war among themselves concerning the part the blood played in disease. The "humoral" pathologists maintained that the blood was the seat of all disease. Much of the popular conceit of our own times regarding "impurities" of the blood is derived from the doctrines of humoral pathology. The impurities, which we are called upon to treat, are, for the most part, impurities of the skin, animal and vegetable parasites, with which the blood has nothing to do, except to nourish their host. The real impurities of the blood are the acute infectious diseases, the germs of which breed in the blood, with characteristic fecundity, feed upon it, disorganise and corrupt it, so that:—

> "The life of all his blood is touched corruptibly."

The blood, as the source of life, has always been recognised as the maternal substitute of the body from which it is derived. The contract for the sale of the soul had always to be signed in blood. So Mephistopheles insists that Faust shall sign his compact with him with a pen dipped in his blood, because as he says of this subtle fluid—a saying to which we are now prepared to agree:—"*Blut ist ein ganz besonderer Saft*" (Blood is a very peculiar juice).

INDEX.

PAGE.

Absorption and assimilation ... 132
Adaptation, force of ... 90
Age, determination of ... 167, 168
  " effect of upon nerve tissue ... 245
  " of the earth ... 59
Air in bone ... 170
Albumen and its products ... 130
  " of the blood ... 269
Alcohol, action of ... 12
Alkalinity as favoring oxidation ... 137
Amœba, the ... 114
Amœboid motion of white blood corpuscles ... 267
Aneurism, Hunter's treatment of ... 4
Animal bodies as machines ... 43
Animals, fertility of ... 94
Appendix vermiformis as rudiment ... 80
Artificial selection ... 90
  " " effects of ... 92
  " construction of organic bodies ... 41
Assimilation, the property of ... 52, 132
Atavism ... 87, 89
Atmosphere, maintenance of composition of ... 43
Aubrey John, remarks concerning Harvey ... 3
Autogeny ... 141
Axis cylinder, the ... 228

Bathybius, the ... 113
Bee, generation of ... 127
Birds, action of muscles in ... 221
  " classifications of ... 92
Blood albumen ... 269
  " and its properties ... 247
  " as source of life ... 272
  " as substitute of the body ... 272
  " coagulation of ... 269
  " color of ... 252
  " constitution of ... 251, 268

Blood corpuscles colored...... 265
" " colorless 266
" " affected by coagulation 270
" " red 259
" " " constitution of 264
" " " elasticity of........ 263
" " " number of..... 263
" " " size of.... 260
" " " use of.. 265
" dependence of muscle on.. 217
" fibrin of, 269
" " use of....................................... 270
" morphology of....................................... 258
" odor of..... 253
" of man and animals,. 71
" oxidation processes in..................................... 136
" plasma..... 268
" proximate principles of 269
" quantity of........ 255
" reaction of.................... 253
" spectroscopy of 265
" taste of...................; 254
" temperature of................. 254
" transfusion of 248
" value of 247 272
" weight of.. 255
" vessels, contractility of.......... 197
Bone, absorption by 172
" air in..... 170
" and its properties.. 150
" as a connective tissue.................. 164
" as fuel...... 158
" as symbol of the body 174
" canaliculi 155
" centres of ossification n.............................. 167
" chemistry of. 156, 159
" corpuscles...... 155
" constancy of composition of.. 159
" distortion effected by weight............... 173
" effects of use and disuse on............ 172
" excavation of 169
" formation in anomalous places.............. 104
" " of............ 165
" general properties of... 152

Bone, harmony of development of........173
  " Haversian canals of........153
  " histology of........153
  " lamellæ of........154
  " marrow of........171
  " studies in living........171
  " preservation of........163
  " phosphate of lime in........162
  " relation to nerve tissue........150
  " resistance and resilience of........159
  " rudiments........78
Brain of man and animals........70, 71
Brambles, classification of........92
Branchial clefts........75

Cadaveric rigidity........212
Canaliculi of bone........155
Cancellated structure of bone........169
Carbon compounds in plants........40
Carbonic acid gas, decomposition of in plants........39
Carotid process, the........233
Cataclysms of Cuvier........58
Caterpillar, colors of........98
Cats and red clover........101
Caul, the........10
Cell, chemistry of........131
  " contents or protoplasm........113
  " derivation and import of the term........110
  " discovery and history of the........108
  " metabolism of........133
  " mode of birth of........144
  " " " death of........145
  " nucleus and nucleolus........112
  " pigment in chameleon........118
  " shape and size of........109
  " wall........111
Centre of ossification........167
Cerebro-spinal and sympathetic systems........226
Cerebrum, action of cells of........239
Chameleon, color changes in........117
Chamisso on alternation of generation........87
Channel of Mt. Pilatus........37
Chemistry of blood........264, 268
  " " bone........156, 159
  " " the cell........131

Chemistry of muscle 184
" " nerve tissue 225
" " protoplasm 128, 131
Child, resemblance of to parent 89, 90
Chorda dorsalis, discovery of cell structure of 110
" " ossification in 167
Cilia and ciliary motion 119
Ciliary motion, conditions affecting 121
Circulation, discovery of 2
" value of knowledge of 4
" work on 2
Classification of tissues 146
" " " anatomical 147
" " " chemical 147
" " " physiological 148
" " animals and plants, difficulty of 91
Clocks, the force which runs 27
Clover, red and cats 101
Coagulation of the blood 269
Coal, magazines of 40
Coccyx as rudimentary organ 78
" muscles of 79
Color changes in chameleon 117
" of blood 252
" " flowers, use of 101
" " muscle 177
" " nerve tissue 226
Colors, protective 97
" warning 97
Combustion, excretions as products of 41
" gases of 41
Comparative anatomy, evidence furnished by 64, 65
" embryology 73
Conservation of force 23
Contraction process as cause of heat of the sun 36
Conservatoire des Arts et des Métiers 29
Contractility of muscle (see muscle)
Convertibility of the forces 26, 29
Corpuscles, blood (see blood).
" bone (see bone).
" of Pacini 230
" of Krause 230
" tactile 230
Cranium, bones of 68

Curare, action on muscle 207
Curve, the muscle 203
Cuvier, cataclysms of 58
" on comparative anatomy 65
" " foot prints 62

Darwin Charles Robert, discoveries of 91
" Erasmus 70
" on imperfection of geological record 63
" views on rudiments 83
Death of cells 145
Decay, action of upon matter 25
Denudation of earth, rate of 58
Diemerbroeck's treatment of small-pox 7
Digestive system, rudiments in 79
Digitalis, action of 12
Disease, ontological conception of 5
Diseases transmitted by inheritance 85
Drinking water, lime salts in 162
Du Bois-Reymond's theory of muscular action 210, 211
Duck, resistance of to asphyxia 266
Dynamometer, the 219

Ear, comparative anatomy of 65
" external as rudiment 81
" lopped in rabbits effect on bones 173
" rudimentary muscles of 79
" the point of as rudiment 81
Earth, age of 59
" effect of arrest of rotation of 35
" past history of 55
Egg (see ovum).
Egg, oxidation processes in 135
Elasticity of muscle 185
Electricity, action of on muscle 201, 203, 204
" action of upon nerve tissue 236
" and nerve force 241
" generation in muscle 209
" light from 31
" motion from 31
Electrotonus of nerve fibre 237
Elements, ultimate composing organic matter 129
Emboli 271
Embryology comparative 73
Endogenous development of cells 144

Epiphyseal centre in femur.......... 168
Equivalence of the forces.......... 28
Ergot, physiological action of.......... 14
Evolution, the theory of.......... 56
Excretions as products of combustion.......... 41
Exercise, influence of on nerve tissue.......... 245
Existence, the struggle for.......... 94, 96
Existing causes, operation of.......... 59
Experience, the fallacy of.......... 4
Eye, rudimentary structure in.......... 81
  " comparative anatomy of.......... 65

Facial bones, air in.......... 171
  " neuralgia nerves affected in.......... 12
Fatigue, effect on muscle.......... 185
  " sensation of.......... 191, 192
Femur, epiphyseal centre in.......... 168
Fertility of plants and animals.......... 94
Fœtus of man and animals.......... 74, 75
Fibrin, blood.......... 269, 270
Filum terminale as rudiment.......... 80
Fire, action of upon matter.......... 24
Fishes, air in bones of.......... 170
Flowers, use of smell and colors of.......... 101
Food and fuel, relative cost of.......... 44
  " as source of force.......... 39
  " force value of.......... 43
  " in relation to work.......... 44
Foot of man and animals.......... 76
Foot prints as evidence.......... 62
Force, conservation of.......... 23
  " machinery a means of changing.......... 27
  " muscular.......... 218, 219
  " nerve, the.......... 237
  " no matter without.......... 25
  " perpetuity of.......... 38
  " physiological.......... 39
Forces, convertibility of the.......... 26
  " equivalence of.......... 28
Fossils, explanations of.......... 56
Fuel, bones as.......... 158
  " and food relative cost of.......... 44

Galvani and galvanism.......... 202
Gases of combustion.......... 41
Gelatine as an aliment.......... 158

Generation, alternation of........ 87
" spontaneous........ 141
Genesis of protoplasm........ 140
Geoffroy St. Hilaire on rudiments........ 82
Geological record, imperfection of........ 63
Germinal vesicle, molecules in........ 89
Gesticulation, action of muscle in........ 222
Gladstone's response........ 16
Goethe, views on development of life........ 69
" Wilhelm, work of........ 68
Gravitation, conversion of into heat........ 37

Hæckel Ernst, work of........ 74
Hair bulbs, terminations nerve fibres in........ 231
Hairs as rudiments........ 80
Haller Albert, sketch of life of........ 19
" works of, opinions concerning........ 21
Hand and its homologues........ 72
Haversian canals........ 153
Harvey William, discovery of the circulation........ 2
" " life of........ 17
Heat caused by gravitation........ 37
" effect on muscle........ 200
" generation of, in muscle........ 208
" mechanical equivalent of........ 29
" motion converted into........ 30
" of sun from contraction........ 36
" solar, origin of........ 25
Hemaglobin........ 264
Hematin........ 264
Heredity (see inheritability).
Histology, history of........ 105
Homœopathy and the school of Naples........ 15
Homochronous transmissions........ 87
Horses, phenomena of reversion in........ 88
Human beings, fecundity of........ 95
Humboldt's estimate of forms of life........ 64
Humerus, supra-condyloid process of........ 78
Hunger as cause of preservation of race........ 103
Hunter John, treatment of aneurism........ 4

Inheritability, examples of........ 85
" explanation of........ 89
" homochronous........ 87
" in lower animals........ 86

Inheritability, influence on the mind........ 239
“ laws of........ 84
Infusoria, fecundity of........ 95
Insects, action of muscles in........ 221
“ winged and wingless........ 96
Intermaxillary process........ 69

Janssens Zacharias and the microscope........ 107
Jellies, nutritive principles in........ 158

Kant, nebular hypothesis of........ 34
King's evil, royal touch as cure of........ 9
Kölliker on the cell........ 112

Lamarck Jean, works of........ 66, 90
Lamellae of bone........ 154
Lanugo as rudimentary structure........ 81
Laplace, nebular hypothesis of........ 34
Laryngismus stridulus a reflex affection........ 12
Lecithin and cerebrin........ 235
Leeuwenhoek, discoveries of........ 107
Leg of man and animals........ 76
Levers, muscles as........ 217
Life, definitions of........ 48
“ period of development of........ 54
Light from electricity........ 31
Lime phosphate in bone........ 102
Links missing, cause of........ 62
Liquor sanguinis........ 268
Locomotive, derivation of force of........ 28

Machinery, a means of changing force........ 27
Machines, animal bodies as........ 43
Madder, absorption of by bone........ 172
Malpighi, discoveries of........ 107
Man, ancient........ 61
“ position of in animal scale........ 72
Marrow of bone........ 171
Matter indestructibility of........ 24, 38
“ no, without force........ 25
Maturity at birth, determination of........ 168
Mechanisms and organisms........ 51
Meckel, ganglion of........ 12
Metabolism of the cell........ 133
Meteors, fall of upon the earth........ 36
Metrorrhagia, ancient treatment of........ 13
Microscope, history of........ 107

Mid-jaw bone 69
Miraculous and non-miraculous theories of life 54
Molecular movements 123
Molecules, size and number of in ovum 89
Molière's satires upon medicine 8
Monkeys, sense of taste in 71
Motion as essence of reproduction 126
  " ciliary 119
  " conversion of into heat 30
  " from electricity, examples of 31
  " molecular 123
  " muscular 176
  " of white blood corpuscles 267
  " property of in protoplasm 116
Mueller Johannes and the chorda dorsalis 110
Muscle, absolute power of 218
  " action of curare on 207
  " " " nerve force on 203, 225
  " " " sulphocyanide of potash on 206
  " " persistence of after death 212
  " and nerve plate 232
  " and its properties 175, 195
  " as levers 217
  " chemistry of 184
  " color of 177
  " connection with tendons 197
  " contractility 195
  " " agents which induce 199
  " " change of form in 198
  " " degree of 198
  " " direct and indirect excitation of 200
  " " effect of 197
  " " independence of 206, 208
  " " electric excitation of 201, 203, 204
  " " thermal excitation of 200
  " " rate of conduction of 206
  " " sound of 205
  " curve 203
  " dependence of upon blood 217
  " difference in different animals 220
  " disks 179
  " elasticity of 185
  " etymology of 175
  " fibre and fibrilla 179

Muscle, force and nerve force 238
" form and shape of 182
" fuel of 25
" general power of 219
" " properties of 180
" generation of electricity in 209
" " " heat in 208
" in birds action of 221
" in insects " " 221
" involuntary 182
" " contractility of 196
" " disposition of 183
" motion effected by 176
" names of 181
" oxidation of 216
" " processes in 135
" oxygen supply to 216
" post-mortem changes in 214
" products of action of 215
" protoplasm 180
" reaction of 184
" rigor mortis of 212
" rudiments 79
" sarcolemma of 178
" sense, exercise of 193
" " and sense of touch 190
" sensibility of 190
" sexual differences in 220
" specific properties of 185
" striped and smooth 176
" termination of nerve fibres in 231
" tonicity of 187, 188, 189
" transfusion of blood into 47
" velocity and delicacy of action of 221
" voluntary, anatomy of 178
" wave, the 205
Muscular force, source of in food 39

Naples, school of and homœopathy 15
Napoleon, advice to Antonamarchi 8
Natural selection 90
" " complications in 100
" " illustrations of 96
Nebular hypothesis 34
Nerve, ancient significance of 244

Nerve and its properties 223
" as tendon 244
" cells 227
" " and fibres 225
" fibres 227
" " axis cylinder of 228
" " course of 232
" " gray 229
" " identity of 234
" " indifference of direction of nerve force in 235
" " medulla of 228
" " motor, terminations of 231
" " sensitive " 230
" " sheath of 227
" force, action of in cold blooded animals 243
" " " " upon muscle 204, 225
" " and electricity 241
" " genesis of 225
" " independence of 224
" " nature of 237
" " rate of conduction of 240, 242
" tissue action of electricity upon 236
" " arrangement of 226
" " chemical processes in 236
" " chemistry of 235
" " color of 226
" " divisions of 226
" " effects of age on 246
" " " " use and disuse 245
" " oxidation in 138
" " prime function of 223
" " reception and perception of impressions by 242
" " relation of bone to 150
" " subordination of 224
Nerves, properties of 229
Nictitating membrane of the human eye 81
Nucleus and nucleolus of the cell 112
" " " " " chemistry of 132
Number of species 94
Nutrition and reproduction 143
" the circle of 42

Occupation, effect of on bones 173
Ophthalmology, progress of 13
Opinions of medicine by noted men 7

Rudimentary organs, muscle........ 79
" " spinal cord........ 80
Salpae, alternation of generation in........ 87
Sarcolemma of muscle........ 178
Schwann Carl Theodor and the cell........ 108
" white substance of........ 228
Science versus practice........ 3
Sea-buoys, alternation of generation in........ 88
Segmentation process of in ovum........ 125
Selection, artificial........ 90
" " effects of........ 92
" natural........ 60
" " complications in........ 100
" " illustrations of........ 96
" " sexual........ 98
Semilunar fold in the eye as rudiment........ 81
Sensibility of muscle........ 190
" " " and sense of touch........ 190
Sense muscular, exercise of........ 193
Sensitive nerves, terminations in muscle........ 191
Sexes, difference of muscle in........ 220
Sexual selection........ 98
Sharpey's bone lamellae........ 154
Sheath of nerve tubes........ 227
Ships and force of the wind........ 28
Signatures, doctrine of in the treatment of small-pox........ 6
Skeleton, the........ 151
Smell of flowers, use of........ 101
Small-pox, doctrine of signatures in........ 6
Sound of muscle contraction........ 205
Solar origin of heat........ 25
Species, mutability of........ 92
Spectroscopy of the blood........ 265
Spermatozoids as ciliated cells........ 122
" action of towards ovum........ 125
" discovery of........ 107
Spinal cord, termination of as rudiment........ 80
" " relation of bone to........ 150
Spontaneous generation........ 141
Starch, formation of........ 26
Steam engine, the force of........ 28
Stephenson George, conception of heat........ 25
Sterne, description of receipt by........ 5
" opinion of medicine by........ 8

Struggle for existence 94, 96
Succession, order of vertebrate 66
Sugar, formation of 26
Sun as the source of force 25, 32
" dimensions of 32
" heat of caused by processes of contraction 36
" origin of forces of 33
Sympathetic and cerebro-spinal systems 226

Tad-poles, cells of chorda dorsalis of 110, 111
Temperature of the blood 254
Tendons and nerves 244
" connection with muscle fibre 197
Theories of life 54, 55
Tic doloureux 12
Tissues, classification of the 146
Tonicity of involuntary muscle 189
" " muscle 187
" " " a reflex phenomena 188
Tooth, wisdom as rudiment 79
Touch, sense and sensibility of muscle 190
" the royal 9
Transfusion of blood 248
" " " into muscles 217

Uterus, resistance to putrefactive change 214
Universe, infinitude of 38

Valves of veins, Harvey's study of 18
Velocity of muscular contraction 221
Vermiform appendix as rudiment 80
Vertebrata, structures peculiar to 268
Vertebrate animals, bone tissue in 150
Vesicle germinal, molecules in 89
Volitional action 238
Virchow's opinion of ophthalmology 13
Virgin generation 126
Vital force, the 210
Vocal cords, muscular movements of 222
Vulpian on brain of man and animals 70

Wall, the cell 111
Warning colors 97
Water drinking, lime salts in 162
" wheels, the force of 27
Wave, the muscle 205
Whale, perception of impressions in 243

Wind, fertilisation by 102
Windmills, the force of 27
Wisdom tooth as rudiment........ 79
Woorara, action on muscle........ 206
Work, relation of food to........ 44

LANE MEDICAL LIBRARY

To avoid fine, this book should be returned on or before the date last stamped below.

F71
W62
1879
Whittaker, J. T.
Physiology. 17526

NAME	DATE DUE